EFFECT OF THE NUMBER OF STEP-UP DIETS FED DURING GRAIN ADAPTATION ON ACIDOSIS AND FEEDING BEHAVIOUR OF FEEDLOT CATTLE

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Abstract

Two trials were conducted to evaluate effects of grain adaptation protocol on subacute acidosis, feeding behaviour and ADG of cattle. In trial one, 12 crossbred heifers (384 ± 25 kg) were stepped from 40% to 90% dietary concentrate by either rapid adaptation (RA; one step-up diet fed for 3 d) or by gradual adaptation (GA; five step-up diets fed for 3 d each). Mean daily ruminal pH variables did not differ ($P > 0.10$) between treatments but variances of a number of ruminal pH variables were greater ($P < 0.05$) for RA than GA during adaptation to 65% and 90% concentrate. Mean hourly pH did not differ over the first 24 h of adaptation to 65% concentrate, but variance of hourly pH tended ($P < 0.10$) to be greater for RA than GA for eight of the first 24 h of adaptation to 90% concentrate. Increased variance in ruminal pH parameters was associated with detection of acidosis in certain individuals. On d 1 of 90% concentrate, ruminal pH tended ($P = 0.07$) to be lower at 11 and 12 h post-feeding with RA than with GA. Ruminal volatile fatty acids (VFA) and osmolality were similar between treatments. In trial two, 120 crossbred heifers (366 ± 23 kg) were adapted from 40% to 90% concentrate. A protocol identical to trial one was used with the addition of moderate adaptation (MA; three step-up diets fed for 3 d each). The increase to 65% concentrate caused reduced daily bunk attendance and increased maximum intermeal interval for RA compared to MA and GA cattle but the increase to 90% did not. ADG was reduced for RA compared to MA or GA during adaptation but over day 1 to 69 ADG did not differ between treatments ($P \geq 0.41$). Current management strategies for preventing acidosis in pens of cattle are based on responses of the most susceptible individuals. Improved

understanding of individual responses to acidotic challenge may allow development of more effective acidosis prevention practices.

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List of Abbreviations

ADF	Acid detergent fibre
ADG	Average Daily Gain
BW	Body weight
Ca	Calcium
Co	Cobalt
CO_2	Carbon dioxide
CP	Crude protein
Cu	Copper
d	Day
DBA	Daily bunk attendance
DM	Dry Matter
g	Gravity
h	Hour
I	Iodine
IU	International units
Kg	Kilogram
KIU	Killo-international units
L	Liter
LDH	Lactate dehydrogenase
M	Molar
MII	Maximum intermeal interval
Min	Minutes
mL	Millilitres
Mn	Manganese
N	Nitrogen
Na	Sodium
NDF	Neutral detergent fibre
P	Probability
PCV	Packed cell volume
SAS	Statistical Analysis Systems
SD	Standard deviation
Se	Selenium
VFA	Volatile fatty acid
vol	Volume
wk	Week
wt	Weight
Zn	Zinc
ºC	Degrees Celsius
%	Percentage

1.0 INTRODUCTION

The feedlot cattle industry in the United States and Canada has developed into an intensively managed system in which grains are fed as the primary source of energy. The practice of feeding high grain diets developed because grains generally provide the least expensive cost per unit of energy when compared to forage. The high energy density of grains makes them much easier to store, process, mix and deliver to cattle when compared with forages. In addition, North American consumers have developed a taste preference for grain-fed beef which promotes grain feeding even on occasions when the energy cost of forage may be more favorable than grains.

Within the rumen, feedstuffs consumed by ruminants are subject to microbial fermentation. Cattle evolved consuming large meals of forages which are fermented at a relatively slow rate. Consumption of these large meals and subsequent microbial fermentation within the rumen is favorable for energy and protein utilization of forages but these same feeding habits create unique challenges when high-grain finishing diets are fed. Microbial fermentation of grains (primarily starch) proceeds rapidly. If a large meal of grain is consumed and fermentation occurs too rapidly organic acids can accumulate within the rumen and cause the rumen to become acidotic (Owens et al., 1998).

Since grains are the primary source of energy provided to finishing feedlot cattle, ruminal acidosis is a major concern for feedlot operators. Acidosis is the most important

nutritional disorder faced in commercial feedlots today and a majority of management recommendations made by feedlot nutritionists are intended to help avoid acidosis and maximize feed intake (Gibb and McAllister, 1999). Feeding management, for prevention of acidosis, is believed to be important whenever cattle consume high-grain diets but the period when cattle initially transition from the consumption of high-forage to high-grain is the time of greatest concern, with respect to development of acidosis (Schwartzkopf-Genswein et al., 2002). Adaptation to high-grain diets has traditionally been managed by feeding cattle a series of sequential diets containing an increasing grain concentration. This is done to allow gradual adjustment of ruminal microbial populations to the consequences of rapidly fermented carbohydrate which helps to prevent the occurrence of acidosis. In commercial feedlots, feeding a large number of step-up diets to facilitate grain adaptation complicates feed delivery and is a significant inconvenience. Therefore, the decision of how many step-up diets are to be fed must balance the imposed risk of acidosis against convenience and efficiency of feed delivery. As a result, opinions vary regarding the number of step-up diets deemed necessary for successful adaptation to occur. Greater knowledge of how the number of diets fed during grain adaptation will affect feeding behaviour, acidosis and subsequent performance would provide additional insight upon which management decisions could be based.

The objective of this review is to focus on the effects of feeding management during grain adaptation on acidosis. Effects of acidosis on feedlot cattle and the role of feeding behaviour in acidosis will also be discussed.

2.0. LITERATURE REVIEW

2.1. Grain Adaptation and Feeding Practices

When cattle first arrive at finishing feedlots they are typically provided with access to a total mixed ration (TMR) receiving diet consisting primarily of forage and a smaller proportion of concentrate. Initially, the feed intake of newly arrived cattle can be very low and some cattle may not attend the bunk at all (Gibb et al., 1999). The introduction of high-concentrate diets to cattle is typically withheld until all cattle have settled into their new surroundings and appear to exhibit a healthy and stable amount of feed intake. Often a period of one to two weeks is required before these objectives are met.

Typical finishing diets contain between 10 to 15% concentrate and in western Canada consist primarily of barley-grain. The introduction of these high-concentrate finishing diets to cattle is typically completed in a gradual manner. Traditionally this has been accomplished by feeding a series of sequential diets containing an increasing grain concentration. Each diet is fed for a number of days and thus dietary concentrate is stepped up to the finishing level. Typically this is completed over a period of between 15 and 30 days (D. J. Gibb., Personal communication). This transition period is the time when cattle encounter the greatest risk for acidosis (Tremere et al., 1968; Elam, 1976; Fulton et al., 1979a, 1979b).

Abrupt diet change from forage to grain has been reported by many researchers to result in ruminal acidosis (Hungate et al., 1952; Krogh, 1961; Allison et al., 1964; Goad et al., 1998). Even when dietary concentrate is increased using a step-up approach, increases in concentrate may still cause acidosis to occur. Using the step-up approach Fulton et al. (1979b) increased dietary grain content from 35 to 90% in 20% increments. On the first day that each of the transition rations were fed, low ruminal pH values were measured. Klopfenstein et al. (2003) also measured rumen pH during grain adaptation and concluded that during the period of grain adaptation, all cattle experience some level of acidosis. Contrary to these results, Coe et al. (1999) rapidly stepped steers from 100% alfalfa to 100% concentrate (25% wheat, 65% corn) in 7 days using a total of 4 diets. During this period, no evidence of ruminal acidosis was found. Ruminal pH remained above 5.5 and L(+) lactate concentration remained below 1 m*M*.

Despite these conflicting results, it is clear that an abrupt change from a forage diet to one containing high quantities of concentrate can result in ruminal acidosis and cause animals to go off feed. However, the point at which the level of grain increase actually becomes too large is far less clear. This lack of clarity has resulted in considerable variation in methods of grain adaptation. Individual strategies vary in the number of step-up rations fed, the number of days of adaptation which are allowed on each step-up diet, in the degree of feed restriction (if there is any) and in a myriad of additional feeding management details. Because of the desire of feedlot operators to minimize feeding of roughage and to get cattle onto the finishing diet as soon as possible, it would be of interest to determine to what extent and by what methods adaptation might be shortened without causing an increased incidence of acidosis.

Weichentahal et al. (1999) and Choat et al. (2002) took a novel approach to grain adaptation and successfully adapted cattle to a high-concentrate diet by gradually increasing a limited intake of that diet. Few problems from acidosis or related intake variation resulted; however, Choat et al. (2002) did emphasize that care must be taken to ensure that the length and degree of the feed restriction is not excessive such that average daily gain (ADG) is inhibited to a point requiring additional days on feed. Evaluation of other parameters such as the effect of the number of step-up rations fed or the number of days that each step-up diet is fed might also provide valuable insight for future management of cattle during adaptation to high grain diets.

2.2. Acidosis

Acidosis is recognized by modern cattle feeders as a significant nutritional disorder which must be minimized through careful management. This disorder occurs as a practical consequence of finishing cattle on diets consisting of highly processed cereal grains which contain low levels of roughage. Britton and Stock (1987) declared that acidosis is not one disorder but instead it is a continuum of degrees of acidosis. This continuum can cause effects as slight as an unobserved reduction in feed intake or as severe as death of the animal. The occurrence of acidosis can easily be prevented by providing diets containing only a high level of roughage but the desire for maximum production efficiency dictates that high-concentrate diets be fed. Most often, cases of acidosis begin with an abrupt increase in the amount of rapidly fermentable starch or carbohydrate consumed by the ruminant animal. Skillful feeding management can help to minimize both the occurrence and severity of acidosis but as long as feedlot cattle are finished on high-grain diets, acidosis will be an important problem. A detailed

understanding of the development of acidosis has been hampered by a low rate of occurrence of this disease and has been further complicated by the many interactive factors which are involved in the development of the condition (Figure 2.1). Feed intake, diet type, microbial populations and feeding behaviour are a few of many influencing factors (Galyean and Eng, 1998). Because of the complexity of this condition an understanding of the etiology of acidosis requires a multidisciplinary approach beginning with an understanding of rumen fermentation.

2.2.1. Ruminal Fermentation

Ruminal microbiota produce extracellular enzyme complexes which degrade plant polysaccharides (cellulose, hemicellulose, pectin and starch). Degradation of polysaccharides within the rumen results in the presence of soluble oligosaccharides and glucose which provide a source of nutrients for ruminal organisms. Microbial fermentation of free glucose yields ATP for microbial growth and VFA which are subsequently used as the primary energy source for the animal.

The primary VFA which are produced within the rumen as an end-product of fermentation are acetate, propionate and butyrate. Accumulation of VFA within the rumen tends to lower the pH of rumen fluid but fortunately these organic acids are readily absorbed by passive absorption through the rumen epithelium (Sharp et al., 1982; Bergman, 1990) for metabolism by animal tissues. As recently consumed feed is fermented, production of VFA may exceed absorption but normally a close balance between production and absorption does not typically allow VFA to accumulate at concentrations sufficient to dramatically reduce ruminal pH. However, following a large meal, minor accumulation of VFA does normally occur resulting in a diurnal fluctuation

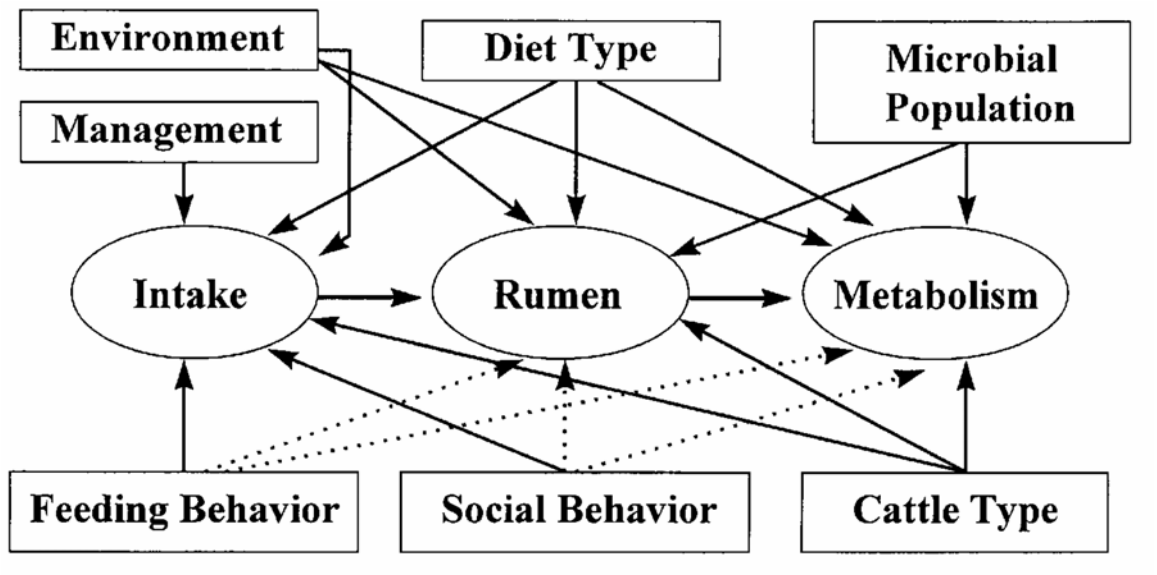

Figure 2.1. Possible factors and interrelationships among factors affecting acidosis in feedlot cattle. Solid arrows indicate relationships known to exist with a high degree of confidence, whereas dotted arrows represent putative relationships. Adapted from Galyean and Eng (1998).

of rumen pH. For animals consuming forage based diets a healthy ruminal pH can normally be maintained. Intake of more readily fermented carbohydrates such as starch contained in cereal grains results in lower ruminal pH. With high-concentrate diets, an increased rate of VFA production and increased accumulation generally reduces mean ruminal pH to between 5.6 and 6.2 (Schwartzkopf-Genswein et al., 2002).

Lactic acid ($pK_a = 3.1$) is more than 10 times as strong an acid as the normal VFA mixture (average $pK_a = 4.8$) produced within the rumen. Ruminal microbes produce two forms of lactate, the D+ and L- form. The L- form can be readily metabolized by the liver and heart tissue but the D+ form is not produced by body tissues and is metabolized more slowly than L-lactate (Giesecke and Stangassinger, 1980). Under normal rumen conditions, bacteria which are capable of lactic acid production (i.e., *S. Bovis*, Lactobacillus spp.) are not overly competitive. Competition against other microbes for substrate limits their growth and accumulation of lactic acid is normally curtailed by lactic acid utilizing bacteria (i.e., *Selenomonas* spp, *Anaerovibrio* spp., *Megasphaera elsdenii* and *Propionibacterium* spp.) and protozoa (i.e., *Entodinium* spp.) (Schwartzkopf-Genswein et al., 2002). The balance between lactate producers and lactate users normally ensures that concentrations of lactic acid within the rumen does not exceed 5 mM (Owens et al., 1998).

2.2.2. Ruminal Events Resulting in Acidosis

During the transition of cattle from high-forage diets to high-concentrate diets, extensive adaptation of the ruminal microbial populations occur. Numbers of fibrolytic bacteria typically decrease and the number of amylolytic bacteria rapidly increase (Goad

et al., 1998). Once adaptation is complete, the number of ruminal bacteria in healthy cattle fed high-concentrate diets is typically 10-fold the number of bacteria found in forage fed cattle (Slyter et al., 1965; Eadie and Mann, 1970; Slyter et al., 1970). During this remarkable transition, stable development of the adapting microflora is believed to be very important if balance is to be maintained within the rumen. However, after transition with stable levels of intake the microbial population typically remains surprisingly constant (Schwartzkopf-Genswein et al., 2002).

Within the rumen, specific strains of ruminal microbes liberate glucose from starch (Owens et al., 1998) and normally the growth rate of other glucose utilizing microbes is limited by the availability of free glucose. Free glucose is typically found only at low concentrations within the rumen. A drastic increase in the availability of free glucose, which occurs when a large amount of rapidly fermentable carbohydrate is immediately introduced into the diet, promotes rapid growth of most bacteria and results in a dramatic increase in VFA production and a decrease in ruminal pH. If the rate of acid production significantly exceeds the rate of acid absorption, due to increased production, inhibited absorption, or reduced dilution, VFA can accumulate within the rumen to deleterious levels, resulting in a potentially drastic pH decline and occurrence of ruminal acidosis (Burrin and Britton, 1986).

While it is known that ruminal acidosis can and most often does occur as a result of VFA accumulation alone, more severe forms of acidosis often involve the additional accumulation of lactic acid which aggravates ruminal pH decline. As with other amylolytic bacteria, when glucose is abundantly available for fermentation, rapid and uncontrolled growth of lactic acid producing bacteria can occur. Normally, populations of

lactic acid producing bacteria seldom exceed 10^7 cells/mL of rumen fluid but when over-consumption of readily fermentable carbohydrate occurs, populations of *S. bovis* alone can quickly reach levels of 10^9 cells/mL of ruminal fluid (Allison et al., 1975). Exponential growth of lactic acid producing bacteria results in excessive production of lactic acid. Lactate producers (*S. bovis* and *Lactobacillus* spp.) are quite tolerant of low ruminal pH but most lactic acid utilizing bacteria are not. If ruminal pH is maintained above 5.5 it appears that equilibrium between production and utilization will exist and lactic acid will not accumulate (Nocek, 1997); however, with pH below 5.5 the pH tolerance differential between lactate producers and utilizers can allow significant accumulation of lactic acid to occur if readily fermentable carbohydrate remains available. When pH falls below 5.2, *S. bovis* and *Lactobacillus* spp. begin to dominate the ruminal environment largely replacing the previously diverse ruminal microflora. If pH continues to decline, growth of *S. Bovis* is also inhibited (Therion et al., 1982) and below pH 4.7 a near monoculture of lactate producing lactobacilli remain in the rumen (Allison et al., 1975). In extreme cases of acidosis ruminal lactate can accumulate to concentrations of greater than 40 m*M* which is considered indicative of severe acidosis (Owens et al., 1998). Lactate can continue to accumulate to levels far exceeding 50 m*M* (Dunlop, 1972; Nagaraja et al. 1985); however, these are extreme cases and it should be remembered that even when acidosis has been experimentally imposed, lactate accumulation seldom exceeds 10 m*M* (Harmon et al., 1985; Burrin and Britton, 1986; Goad et al., 1998; Hristov et al., 2001; Ghorbani et al., 2002).

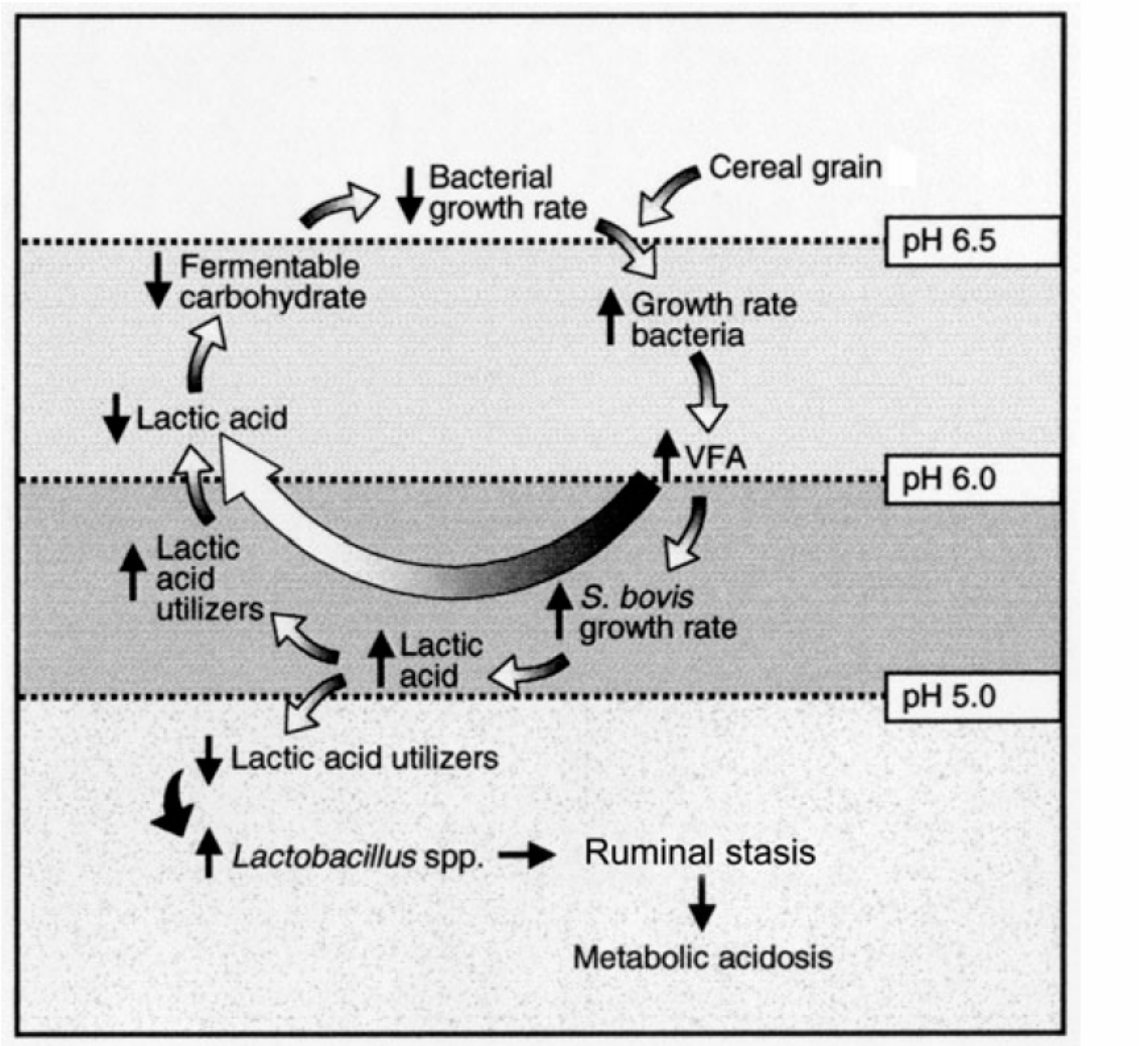

Figure 2.2. Metabolic consequences of concentrate intake in finishing feedlot cattle on ruminal pH and microbial populations of the rumen. Note that in the majority of animals ruminal pH decreases below 6.0 without a significant increase in ruminal lactic acid concentration or in numbers of *Streptococcus bovis* in the rumen. Taken from Schwartzkopf-Genswein et al. (2002).

The previously discussed series of events is illustrated in Figure 2.2. It is important to recognize that grain overload does not cause this series of events to occur in all cattle. Instead it is normally only select individuals or a small subset of cattle, which appear predisposed to acidosis, that are unable to reverse the effects of pH decline who suffer from lactate accumulation and severe acidosis. Factors which may potentially predispose these individuals to acidosis will be discussed later in this review.

2.2.3. Acute and Subacute Acidosis

If at any point, along the continuum of acidosis, ruminal substrate limits microbial growth and acid production to a level which the animal can manage, ruminal pH decline will stall and ruminal pH levels will begin the return to pre-feeding levels. Thus the degree to which acidosis is encountered can be highly variable. In an attempt to reflect differing degrees of acidosis encountered, the disorder has been separated into acute and subacute forms.

No true line of demarcation exists between these forms of acidosis but for the purpose of classification various pH thresholds have been arbitrarily set to define acute and subacute acidosis. Thresholds of subacute acidosis which have been used include daily mean pH below 5.5 (Hibbard et al., 1995; Reinhardt et al., 1997), 5.6 (Owens et al., 1998; Cooper et al., 1999), 5.8 (Beauchemin et al., 2001; Ghorbani et al., 2002; Koenig et al., 2002), and 6.0 (Bauer et al., 1995; Krehbiel et al., 1995). The pH thresholds of acute acidosis which have been used include pH below 5.2 (Cooper and Klopfenstein, 1996; Owens et al., 1998) or pH below 4.5 (Dunlop, 1972).

2.2.3.1. Measurement of Ruminal pH

Because ruminal pH has been extensively used in research as an indication of acidosis, some discussion of techniques for measurement of pH is necessary. Traditionally, mean ruminal pH has been calculated as the average of spot samples collected during the day, but more recently the use of indwelling electrodes has allowed the more accurate, continuous measurement of rumen pH over extended time periods (Krause et al., 1998; Cooper et al., 1999; Beauchemin et al., 2003). With this method, measurement of mean, maximum and minimum pH is more accurate than with spot sampling techniques and the time and degree to which ruminal pH is below a pH threshold can be calculated and used to more accurately reflect changes which occur in diurnal pH fluctuations than was previously possible. The time or degree to which pH is less than 5.5, 5.6 and 5.8 have been recently used to compare the effects of treatments on acidosis (Cooper et al., 1999; Beauchemin et al., 2003; Ericksen et al., 2003; Schwartzkopf-Genswein et al., 2003).

2.2.4. Ruminal Osmolality

A major decline in pH is often recognized as the major ruminal consequence of acidosis but acidosis also has a critical effect on ruminal osmolality. The primary solutes found in rumen fluid are minerals, VFA, lactate, and glucose; thus normal ranges of ruminal osmolality vary by diet type. Garza et al. (1989) reported ranges of 240 to 265 m*M* when roughage based diets were fed and ranges of 280 to 300 m*M* when high-concentrate diets were fed. During acidosis osmolality can increase greatly. During an experiment involving grain engorgement, Owens et al. (1998) measured ruminal

osmolality as high as 515 m*M*. When ruminal osmolality substantially exceeds blood osmolality (285 to 310 mOsm/L), water from the blood is drawn inward through the ruminal epithelium. Rapid water influx swells ruminal papillae and causes physiological damage resulting in patches of the ruminal epithelium being pulled into the rumen (Eadie and Mann, 1970). This provides a blood entry site for ruminal microbes which are later responsible for liver abscesses. Regenerated epithelial tissues will be thickened (hyperkeratosis or parakeratosis) which may inhibit the rate of subsequent VFA absorption (Krehbiel et al., 1995). Shorter term effects of rumen hypertonicity include inhibited digestion of starch and fiber, reduced frequency of ruminal contractions and inhibited feed intake (Carter and Grovum, 1990).

2.2.5. Systemic Acidosis

During severe cases of acidosis, effects are not confined to the digestive tract. Blood variables can also be seriously affected. Blood pH is dependent upon relative concentrations of bases, acids and buffers. When high concentrations of acid within the rumen accumulate to a sufficient level, the capability of the ruminal wall and liver, for metabolizing acid can be overcome resulting in high acid concentrations within the peripheral blood. Base excess is normally present in blood but high acid load can decrease base-excess and if acid accumulation is sufficient it can overcome the bicarbonate buffering system (Owens et al., 1998) resulting in low blood pH. In addition to low blood pH, severe acidosis may cause blood osmolality to increase due to fluid from blood being pulled into the rumen by high ruminal osmolality. Increased blood osmolality is also due to the direct effect of acids accumulating within blood.

Consequences of low blood pH and high osmolality are life threatening. If the animal is unable to restore blood homeostasis and blood pH drops below 7.0 death will likely result (Aslan et al., 1995). Even when homeostasis is restored and death is averted, long term effects on the animal can result in a reduction of subsequent productivity (Galyean, 2001).

2.2.6. Differences in the Susceptibility of Cattle to Acidosis

Considerable variation appears to be evident in the ability of feedlot cattle to cope with a carbohydrate challenge (Dougherty et al., 1975; Brown et al., 2000). Acidosis can generally be induced by an immediate switch from feeding a diet of high-forage to feeding high-concentrate (Goad et al., 1998; Coe et al., 1999) but even with such a large concentrate increase, the ruminal pH response of individual animals has been reported to be highly variable (Bauer et al., 1995). For research purposes, the attempt to create acidosis with minimal variation in ruminal pH response has resulted in techniques such as manual dosing of carbohydrate directly into the rumen and late feeding or fasting of cattle prior to introduction of the challenge diet. While use of these methods appears to increase both the occurrence and uniformity of resultant acidosis they certainly do not eliminate individual animal variation. Even when a challenging dose of highly fermentable carbohydrate has been administered on a body weight basis (to reduce variation) marked variation in animal response has been reported (Huber, 1971; Dougherty et al., 1975; Suber et al., 1979; Brown et al., 2000). Following a 1 day fast, Brown et al. (2000) intraruminally dosed five hay adapted steers with steam flaked corn at 3.0% of body weight. Two of the steers became acutely acidotic and were removed from the trial due

to in appetence (one steer was euthanized, the second steer recovered). In contrast to this, out of the five steers two others did not exhibit any clinical signs of acute or subacute ruminal acidosis. Likewise, when Dougherty et al. (1975) intraruminally administered 70 g of grain (75:25 whole shelled corn:whole oats)/kg of body weight to three steers two of the steers experienced acute acidosis (one was euthanized) but the third steer did not become acidotic (pH did not decline below 5.5).

Even well after the period of grain adaptation an incredible amount of variation remains in the ability of cattle to metabolically cope with high-concentrate diets. The individual ruminal pH of seven feedlot steers fed a high-grain finishing diet was reported by Schwartzkopf-Genswein et al. (2002). Even for these steers who were well adapted to a high-concentrate diet, large variations in rumen pH patterns were reported.

2.2.7. Potential Causes for Differences in Individual Animal Susceptibility to Acidosis

There is no easy explanation for the large variation which exists in susceptibility of individual animals to acidosis. The cause of ruminal VFA accumulation is probably multi-factorial. Factors which have been suggested to be involved include rate of VFA absorption, rate of VFA passage to the lower tract, ruminal buffering capacity and ruminal motility.

2.2.7.1. Rate of VFA Absorption

An explanation of why VFA accumulation occurs and why some animals seem more susceptible to acidosis than others is not easily provided by acid absorption.

Generally VFA are absorbed through the rumen wall in the undissociated form by passive absorption (Ash and Dobson, 1963). Because most VFA within the rumen normally exist in the dissociated form, prior to VFA absorption, hydration of CO_2 at the rumen wall forms HCO_3 and provides a proton for transforming the dissociated VFA into the more readily absorbed undissociated form (Bugaut, 1987). A reduction of ruminal pH results in an increased proportion of ruminal VFA in the undissociated form which would be expected to result in an enhanced rate of VFA absorption through the ruminal epithelium (Masson and Phillipson, 1951). Because lower pH should increase VFA absorption, lower pH should theoretically help to ameliorate VFA accumulation within the rumen and help to prevent acidosis from occurring.

Effects of perakeratosis, other tissue damage, or genetic factors which reduce ruminal VFA absorption is one possible explanation for high variation in susceptibility to acidosis. The omasum, abomasum, and large intestine all efficiently absorb VFA (Stevens, 1973a, 1973b; Stevens et al., 1980) but if the passage rate of VFA from the rumen to the lower tract is low, reduced ruminal absorptive capacity could potentially allow excessive ruminal accumulation of VFA to occur. As cattle adapt to diets which contain a higher proportion of concentrate the length and number of ruminal papillae increase. This results in an enhanced absorptive capacity of the rumen. Full adaptation of ruminal papillae is not immediate and may require up to 8 weeks (Dirksen et al., 1985). If non-dietary factors such as genetics also affect or limit the development of ruminal papillae, the resultant reduction in VFA absorption potential of some animals could help to further explain differences in susceptibility to acidosis. However this is only speculation.

2.2.7.2. Rate of VFA Passage to the Lower Digestive Tract

A considerable fraction of VFA passes from the rumen and is absorbed post-ruminally (Allen, 1997). Reported estimates of the fractions of VFA passed through the omasal orifice are 15 to 20% for calves (Edrise, 1977) and from 29 to 35% for dairy cows (Dijkstra, 1993; Tamminga and Van Vuuren, 1998). The extent to which passage rate varies between animals on similar diets is not known. If the variability of passage rate is high between individual animals a reduced rate of passage may also be implicated in increased susceptibility of certain individuals to acidosis.

2.2.7.3. Buffering within the Rumen

Rumen pH represents the relative concentrations of acids, bases and buffers within the rumen. The primary ruminal base is ammonia and the primary ruminal buffers are bicarbonate and phosphate. When rumen pH falls below 5.0 VFA and lactate can also act as buffers within the rumen (Counette et al., 1979). However below pH 5.0 lactate production is also primarily responsible for the increased ruminal hydrogen ion concentration (Owens et al., 1998).

Consumption and rumination of high-forage diets can result in production of 110 to 170 L of saliva per day (Kay, 1966). This large volume of fluid helps to dilute the acidity of ruminal contents. In addition, buffers in saliva can help to maintain pH in local microbial microenvironments that are favorable to fermentation (Carter and Grovum, 1990). This helps to ameliorate negative effects of low ruminal pH on ruminal microbes. Intake of high-concentrate diets provides less stimulation for saliva secretion and results in production of only 60 to 70% of the saliva produced in cattle consuming a similar

amount of forage (Bailey, 1961). The low rumen pH of cattle fed high-concentrate diets was explained by Davis et al. (1964) to occur as a direct result of decreased saliva production which results in decreased ruminal buffering capacity. However, saliva only provides approximately half the bicarbonate which enters the rumen, the remainder is derived from the blood (Owens et al., 1998). In addition, the concentration of sodium plus potassium is surprisingly constant with differing diets (Johnson et al., 1989) and ruminal microorganisms produce CO_2 at a rapid rate even when pH is low (Blaxter, 1962). There has been little direct demonstration that high-concentrate diets actually depress rumen buffering capacity. More recently, Russell and Chow (1993) have argued that major changes in ruminal buffering capacity as a result of feeding high-concentrate diets seems unlikely.

Rumen buffering capacity may still help to explain differences in the susceptibility of individual animals to acidosis if there is large variation in the amount of daily saliva secretion between animals or if animals vary in the amount of dietary fiber needed to stimulate saliva production.

2.2.7.4. Ruminal Motility

The presence of particulate material within the rumen triggers ruminal movements. When cattle are fed concentrate they do not ruminate as often as forage-fed cattle (Church, 1969). Russell and Chow (1993) explained that because absorption of VFA is a passive process (Ash and Dobson, 1963), increased rumen movements should increase the transfer of VFA from the rumen to the epithelial surface and thus increase the rate of absorption. Therefore, reduced rumination exhibited by cattle fed high-

concentrate diets may also help to explain VFA accumulation and differences in individual animal susceptibility to acidosis.

2.3. Effects of Acidosis

Effects of acidosis on feedlot cattle are highly variable. Effects can be as small as an unnoticed reduction in feed intake or may be as large as to result in death of the animal. Reduced feed intake, increased variation of feed intake and reduced growth performance are common results of acidosis. Acidosis has also been implicated in the development of additional disorders of feedlot cattle including rumenitis, liver abscesses, laminitis and polioencephalomalacia (Brent, 1976; Galyean et al., 2001). The effects of acidosis on feed intake, growth performance and liver abscesses will be discussed in further detail.

2.3.1. Reduced Feed Intake and Increased Feed Intake Variation

Fulton et al. (1979a, 1979b) reported that low ruminal pH (pH < 5.6) inhibits feed intake and demonstrated that subclinical acidosis may manifest as low feed intake and/or intake fluctuations. Brown et al. (2000) reported a high positive correlation between the lowest daily ruminal pH of cattle and their feed intake on the following day. This indicates that low pH (acidosis) may result in a short term reduction of subsequent feed intake. Schwartzkopf-Genswein et al. (2002) reported that for some animals subsequent intake can be compromised when rumen pH is low. To demonstrate this, these authors graphed rumen pH and feed intake of a single steer (Figure 2.3). For this steer DMI was drastically reduced on day 3 following the very low rumen pH on day 2. Often, cattle will

quickly resume a high level of feed intake once ruminal pH is fully restored which can lead to repeating bouts of acidosis and cause a cyclic pattern of feed intake. These erratic patterns of feed intake resulting from low rumen pH have been reported by several researchers (Fulton et al., 1979a; Bauer et al., 1995; Stock et al., 1995). In general, reduced and erratic feed intake patterns have been widely accepted in both industry and research as good indicators of the degree of acidosis which occurs.

2.3.2. Effects of Acidosis on Growth Performance

As discussed, severe acute acidosis can result in death and less severe cases of acidosis can result in a reduction of growth performance which can be difficult to quantify. When researchers have examined the effects of subacute acidosis occurring over the feeding period (Stock et al., 1990; Larson et al., 1993) weight gains and efficiency of feed conversion have been reduced. Over the feeding period, reduced efficiency resulting from subclinical acidosis is believed by industry personnel to result in economic losses as large as $15 to 20 per animal (Schwartzkopf-Genswein et al., 2002) but again the actual economic losses associated with acidosis are difficult to assess. Little information currently exists in the literature regarding the effects of acidosis during the period of grain adaptation on subsequent performance of cattle.

2.3.3. Liver Abscesses

The occurrence of ruminal acidosis is recognized to be closely associated with the occurrence of liver abscesses. The high ruminal acidity and, in particular, the high hypertonicity of ruminal contents occurring during acidosis often result in rumenitis and

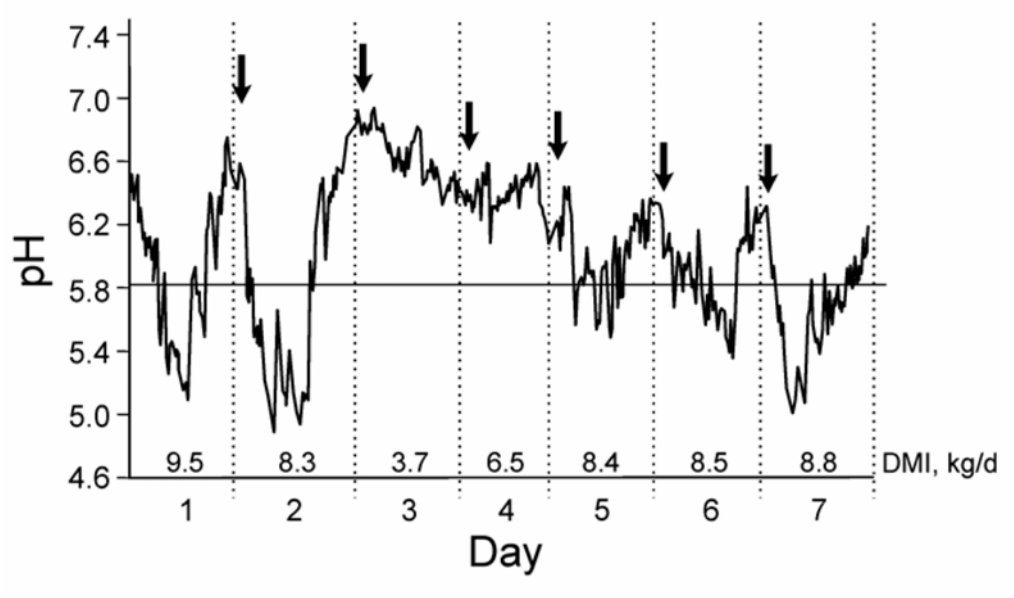

Figure 2.3. Ruminal pH and DMI of a single steer given continual access to a barley-based finishing diet over a 7-day period. Arrows indicate feed delivery times. Taken from Schwartzkopf-Genswein et al., (2002).

perakeratosis of the ruminal papillae (Ahrens, 1965; Engelhardt, 1966, cited by Dirksen, 1970; Owens et al., 1998). Rumenitis and perakeratosis cause clumping and necrosis of the ruminal papillae (Orskov, 1986). It is believed that ruminal lesions formed as a result of acidosis, allow the ruminal microbes responsible for liver abscesses (*Fusobacterium necrophorum*) direct access into the portal system and subsequent entry into the liver. The incidence of liver abscesses in most feedlots typically ranges from 12 to 32%. The liver represents approximately 2% of carcass weight and is a valuable part of the carcass. Affected livers are condemned at slaughter and represent 46% of total liver condemnations (Nagaraga and Chengappa, 1998). The economic loss of condemned livers is significant but a greater loss is believed to result from reduced gain and reduced feed conversion efficiency in cattle with severely abscessed livers (one or more large, active abscesses) (Brink et al., 1990).

2.4. Factors Affecting the Incidence of Acidosis

2.4.1. Dietary Factors Affecting the Incidence of Acidosis

A host of dietary factors are known to exert an impact on the incidence and severity of acidosis. Some of the most influential dietary factors include the level of dietary forage, type of grain fed, extent of grain processing and the feeding of ionophores.

2.4.1.1. Level of Dietary Roughage

From previous discussion it should be quite clear that the level of roughage in the diet is an extremely important factor affecting the incidence of acidosis. The inherent buffering capacity of roughage and its ability to stimulate chewing and saliva flow aid in moderating ruminal pH. In general, as the level of dietary roughage increases the incidence of acidosis decreases. Owens (1987) reported that including 5 to 15% roughage in finishing diets can reduce the incidence of subacute acidosis. This reduction of acidosis due to inclusion of roughage has been reported to improve feed efficiency and gain (Stock et al., 1990) when certain grains are fed.

2.4.1.2. Grain Type

The rate at which grain is fermented within the rumen also influences the incidence of acidosis and subsequent animal performance (Stock et al., 1987). Primary factors affecting ruminal fermentation rate include the type of grain provided and the extent to which the grain has been processed. The relative rates of ruminal starch digestion, for grains fed to feedlot cattle are depicted in Figure 2.4.

Within the rumen, wheat and barley demonstrate the fastest rates of starch digestion, whereas dry whole corn and dry rolled grain sorghum generally exhibit the slowest rates of starch digestion. Absolute rates of digestion vary within grain types due to environment and genetics. The degree of processing can also alter rate of fermentation. Grains with the highest rates of ruminal starch digestion also generally exhibit the greatest extent of ruminal digestion. For grains with lower rates of ruminal starch digestion, an increased proportion of starch generally escapes ruminal digestion and is subsequently digested in the small and large intestines or escapes digestion and is

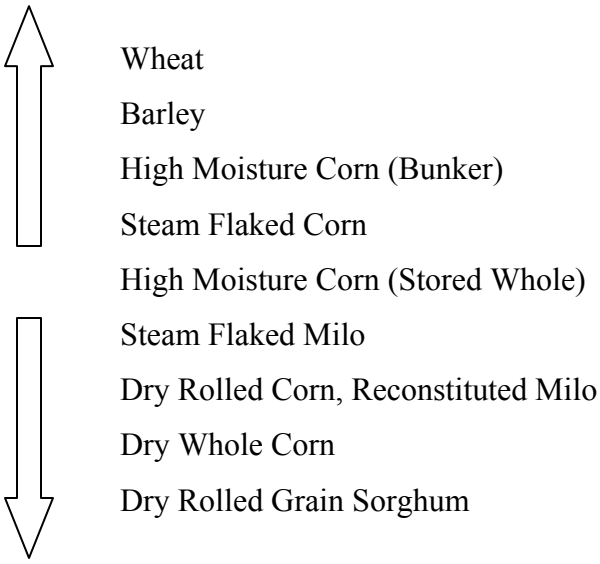

Figure 2.4. Grains Ranked by Rate of Ruminal Starch Digestion. Adapted from Klopfenstein et al. (2003).

excreted in the feces. Thus, in addition to the amount of grain consumed other grain characteristics such as rate of grain digestion within the rumen also have a major influence on the occurrence of ruminal acidosis (Stock et al., 1987; Huntington, 1997). Grains which exhibit the fastest rates of grain digestion generally result in the highest incidence of acidosis. Because the majority of cattle in western Canada are finished on diets composed primarily of barley-grain, acidosis is of particular concern to cattle feeders in this region.

2.4.1.3. Extent of Grain Processing

Processing of barley grain improves its utilization by cattle (Mathison, 1996). The degree to which barley grain is processed prior to feeding also influences the incidence of acidosis. Koenig et al. (2003) stated that "the intent of grain processing is to optimize energy or starch availability in the rumen by maximizing the extent of ruminal carbohydrate digestion while controlling the rate at which it is digested to control digestive and metabolic disturbances". In general, a high degree of ruminal digestion is desirable for production efficiency but if processing of barley-grain is extreme, a high rate of digestion caused by excessive amounts of fine particles can cause a greater degree of acidosis to occur. Excessive processing of barley grain can reduce ruminal pH (NRC, 1996), lead to rumenitis (Hironaka et al., 1979), cause a greater degree of liver abscesses (Cheng and Hironaka, 1973) and eventually result in reduced rates and efficiency of gain (Hironaka et al., 1992). In commercial feedlots, dry-rolling is the primary method of processing barley grain; however, temper-rolling is preferred by some producers because it helps to minimize the amount of fines and helps to control the resulting kernel

thickness (Beauchemin et al., 2001). To help achieve an optimal and uniform degree of processing, a barley processing index [(vol wt of barley after processing/vol wt before processing) × 100] has been developed (Yang et al., 2000). There is considerable controversy regarding the optimal degree of barley processing and it has recently been demonstrated that the optimal processing index (PI) is dependent upon the amount of effective fiber in the diet (Koenig et al., 2003). In commercial feedlots, for high-concentrate barley based diets the PI for rolled barley grain ranges between 70 and 95% (Beauchemin et al., 2001).

2.4.1.4. Ionophores

Ionophores can be an important tool in management of acidosis. The ionophore monensin has been reported to decrease variation in day to day feed intake (Burrin et al., 1986; Stock et al., 1995), cause cattle to eat more frequent and smaller meals (Chirase et al., 1992; Laudert, 1995; Fanning et al., 1999), decrease feed intake (Goodrich et al., 1984; Stock et al., 1995a), inhibit production of lactate within the rumen (Coe et al., 1996; Owens et al., 1998) and increase ruminal pH of cattle fed high-concentrate diets (Nagaraja et al., 1982; Burrin and Britton, 1986). The combined influence of these effects from feeding monensin decreases the likelihood and modulates the effects of acidosis (Nagaraja et al., 1982; Burrin and Britton, 1986). Thus, feeding of monensin during grain adaptation may help to facilitate an uneventful transition. The ionophores laidlomycin propionate and lasalocid do not appear to have any major effect on feed intake (NRC, 1996) and unfortunately their ability to inhibit acidosis has not been as well documented as for monensin.

2.4.2. Feeding Behaviour

A complex relationship exists between feeding behaviour and acidosis. Previous discussion in this review has established that acidosis can affect feeding behaviour (e.g., feed intake, variation in feed intake). The reverse is also true. It is believed that in some cases feeding behaviour may play as large a role in the development of acidosis as does the type and amount of food consumed by the animal (Zinn, 1994; Voisenet et al., 1997; Owens et al., 1998; Grant and Albright, 2001). Eating rates of cattle are not constant (Kenwright and Forbes, 1993; Gibb et al., 1998a; Prawl et al., 1998). Rather, they are adapted to pressure and competition for food at the feed bunk. An example of this is provided by Stricklin (1986) who recorded the feeding behaviour of 15 bulls. Bulls were fed either from a single stall or from a bunk which provided enough space for all bulls to feed simultaneously. In response to increased pressure at the single stall, eating rates of the stall fed bulls increased. For feedlot cattle, faster eating rates and consumption of larger meals can result in lower and more variable ruminal pH (Fanning et al., 1999) and lead to acidosis.

Basic patterns of feeding behaviour in cattle appear to be highly repeatable (Dulphy et al., 1980; Stricklin, 1984; Hicks et al., 1989). With ad libitum feeding these repeatable patterns are typically diurnal with peak periods of feed consumption occurring in the early morning and early evening (Chase et al., 1976). Eating patterns are also related to the temporal and spatial distribution of feed. Delivery of new feed acts as a stimulus for feed intake (Dulphy et al., 1980; Sowell et al., 1998) and feed availability is obviously another important factor which can influence feeding behaviour. Due to effects on eating rates and meal patterns, certain aspects of bunk management such as frequency

and timing of feed delivery, the amount of bunk space allocated per animal, and ad libitum feeding vs. some degree of feed restriction can influence ruminal pH and acidosis. An opportunity for these factors to significantly affect the opportunity for acidosis to occur may be especially high during grain adaptation because the risk for acidosis during this period is already increased.

2.4.2.1. Effects of Feeding Management on Feeding Behaviour and Acidosis

Typically the highest percentage of animals observed eating in a pen coincides with times of feed delivery (Hicks et al., 1989). This has been interpreted to mean that feed trucks stimulate cattle to eat. It has been presumed by many that increasing the number of feed deliveries per day will increase the number of meals which cattle consume, and decrease the opportunity for binge feeding and acidosis which in turn will improve animal performance. Accordingly, Soto-Navaroo (2000) reported that once daily feeding tended ($P < 0.10$) to result in a lower rumen pH than when the same diet was fed twice daily. This suggests that twice daily feeding results in a more stable ruminal environment which may decrease the incidence of ruminal acidosis. Performance results of once vs. twice daily feeding have reported improved efficiency of gain for cattle fed twice daily (Pritchard and Knutsen, 1995) but a performance response is not always evident (Hanke et al., 1981; Pritchard and Knutsen, 1995).

The amount of bunk space allocated per individual animal is another factor which may influence the opportunity for acidosis to occur. If a restricted amount of bunk space is allocated, increased pressure at the feed bunk may result in an increased rate of intake (Stricklin, 1986) and a lower minimum rumen pH would be expected.

Bunk management regimes used for finishing feedlot cattle can be broadly separated into two types. These types are those which provide continual access to feed (ad libitum feeding) and those which involve some level of regulation or restriction of feed available to the animal. Management of ad libitum feeding attempts to maximize feed intake on a daily basis and focuses to ensure that feed is always accessible by cattle. It is presumed that increased competition for feed resulting from delivery of a restricted amount of feed can dictate an upper limit of daily DMI and help to prevent occurrence of the cyclic feed intake patterns, described by Fulton et al., (1979a), which are associated with acidosis. Based on this presumption, rather than attempting to maximize feed intake on a daily basis, regulated or restricted feeding programs attempt to maximize feed intake over the course of the entire feeding period (Galyean, 1999) by minimizing the occurrence of acidosis. Variation in total daily feed intake is reduced when feed is restricted (Zinn, 1995) and this may decrease acidosis. But this method of feeding also typically results in animals becoming meal eaters (consuming a few large meals) (Schwartzkopf-Genswein et al., 2002) and it has also been observed that when cattle are given restricted access to feed eating rates increase (Gibb et al., 1998; Prawl et al., 1998; Schwartzkopf-Genswein et al., 2002). Fanning et al. (1999) reported that increased eating rates and larger meals resulting from restricted feeding resulted in a lower and more variable ruminal pH than was observed for ad-libitum fed cattle. Although the total effect of regulated or restricted feeding management on acidosis remains unclear this type of management has gained widespread acceptance by feedlot managers and consulting nutritionists.

2.4.2.2. Changes in Feeding Behaviour During Grain Adaptation

Gradual adaptation to high-concentrate diets may allow cattle time to adjust feeding behaviour in a way which can help to prevent acidosis. Fulton et al. (1979a) adapted cattle from 35 to 90% concentrate using three step-up diets. As the level of dietary grain increased the rate of feed consumption decreased. Bauer et al. (1992) reported that as steers were adapted to a 100% concentrate diet (12 days using three adaptive diets), daily patterns of DMI changed from consumption of large meals after feeding to a more frequent consumption of smaller meals. It can be concluded that during grain adaptation cattle learn to consume high-grain diets more slowly in order to prevent acidosis (Klopfenstein et al., 2003). Reduced eating rates and consumption of smaller meals should reduce the risk of acidosis (Fanning et al., 1999). One benefit of gradual adaptation may be that cattle are allowed time to learn to reduce eating rates prior to consumption of the final high-grain diet which reduces the opportunity for acidosis to occur.

2.4.2.3. Measurement of Feeding Behaviour

If the effect of feeding behaviour on acidosis is to be further understood then measurement of feeding behaviour is essential. Measurement of feeding behaviour is a challenging endeavour. Under commercial feeding conditions daily feed intake (the average for the pen) is the only objective measurement of feeding behaviour obtained. When the amount of feed provided to cattle is limited many cattle feeders will also record a subjective score of the level of motivation or aggression with which cattle approach the

feed bunk. The measurement of additional feeding behaviours is more difficult and is typically completed in research settings only.

The conventional research method for measurement of the feeding behaviours of cattle consists of visual sampling techniques (Mitlohner et al., 2001). Feeding behaviours which can be measured using visual sampling techniques include but are not limited to the number, frequency and distribution of visits to the feedbunk, feeding duration and the duration of visible ruminating activity. Because of the large number of cattle typically housed in feedlot pens, accurate collection of behaviour data using this method is challenging.

Modern technologies have significantly improved our ability to measure feeding behaviour of cattle. Researchers (Schwartzkopf-Genswein et al., 2002; Herskin et al., 2003) have recorded visual feeding behaviour using video surveillance equipment. This approach provides an improved opportunity for collecting continuous feeding behaviour data and reduces the required amount of time investment. Radio frequency technology is another powerful tool which has been incorporated into electronic feed bunk monitoring systems such as the GrowSafe® feeding behaviour system (GrowSafe Systems Ltd., Airdrie, AB). This system allows automated collection of individual animal bunk attendance information for cattle fed in a group (McAllister et al., 2000) and has been used by researchers (Gibb et al., 1998; Sowell et al., 1998; Schwartzkopf-Genswein et al., 2004) to obtain valuable feeding behaviour information aimed to improve our understanding of potential relationships which exist between feeding management, feeding behaviour, and subsequent animal performance.

2.4.2.3.1. Measurement of Feed Intake

Knowledge of feed intake is an important component of acidosis research. It is important to understand and distinguish between different types of intake measurement. Intakes recorded for group fed cattle are almost always pen-averaged intakes. Because of the effect of averaging, pen-averaged intakes should not be assumed to be indicative of intake by each of the animals within that pen. The danger of this assumption has been demonstrated by Stock et al. (1995) who reported that apparent variation in feed intake was reduced 5 to 10 fold when the intakes of 12 individually fed steers were averaged as if they had been fed together in one pen. Drastic changes in pen intake do not occur until a large percentage of cattle within the pen are affected in a similar manner; however, dramatic decreases in pen averaged feed intake do occur and have been accepted by commercial cattle feeders to indicate acidosis. Patterns of feed intake have also been widely embraced with the degree of erratic intake serving as a gauge of the level of subacute acidosis occurring in commercial feedlot cattle (Schwartzkopf-Genswein et al., 2002).

To get a true understanding of what is going on in the pen, an understanding of individual intake patterns and their impact on performance is needed. As such there is a need to monitor the intake of individual cattle. The feeding of individually housed steers is the simplest and least expensive method of measuring individual animal feed intake and this technique has been widely used in research. Unfortunately, individual housing of cattle removes cattle from the social effects of large groups and may cause feeding behaviour and intake to differ from that observed with group fed cattle (Nielsen, 1999).

The desire to measure individual feed intake among group fed cattle led to the development of automatic systems such as Calan gates and the Pinpointer system (Cole, 1995). However, interference with natural expression of feeding behaviour caused by the design of these systems again limits the value of findings for direct application in industry. Development of the GrowSafe® feed intake system is one of the most recent improvements in our ability to measure feeding behaviours and intake. This system uses radio frequency technology to enable electronic collection of bunk attendance and feed intake for all individual animals within a pen of cattle (Hickman et al., 2003). Although some disruption of typical feeding behaviour may still occur, this system more closely replicates commercial feeding conditions than previous systems and provides valuable feeding behaviour and intake information.

Results obtained using the GrowSafe® feeding behaviour and/or feed intake systems have revealed large differences between feeding patterns of individual cattle even within the same pen (Gibb et al., 1998; Hickman et al., 2002; Schwartzkopf-Genswein et al., 2002). The extent to which these differences in feeding patterns can affect the incidence of acidosis is not yet clear.

2.5. Summary of Literature Review

Acidosis is the most important nutritional disorder faced in finishing feedlots. This disorder is a major concern for feedlot operators and the majority of management recommendations made by consulting nutritionists are intended to help avoid acidosis and to maximize feed intake. Acidosis occurs in conjunction with consumption of an excessive amount of rapidly fermentable carbohydrate which can cause unrestricted

growth of certain ruminal microbial populations and result in excessive production of VFA and/or lactic acid. As this occurs, ruminal pH can decline drastically and result in acidosis. Depending on severity, acidosis can result in decreased feed intake, decreased performance, rumenitis and liver abscesses. During severe cases of acidosis absorption of excessive acid into the blood stream can lead to systemic acidosis and may cause death of the animal.

The risk for acidosis is especially high during the adaptation of cattle from high-forage to high-concentrate diets. Grain adaptation is normally managed by feeding a series of sequential diets with increasing grain concentration. This complicates feed delivery and reduces delivery efficiency. Management practices such as the amount of time allowed and the number of diets that will be fed during adaptation, attempt to balance risk of acidosis with efficiency of feed delivery. The point at which the level of grain challenge becomes too large is not clear. An abrupt change in the amount of concentrate fed can cause acidosis but even with a gradual increase some cattle experience some degree of ruminal acidosis.

Considerable variation is evident in the ability of cattle to cope with a carbohydrate challenge. Even with an immediate switch from forage to concentrate feeding all animals do not become acidotic. The reason for differences in animal susceptibility to acidosis is not easily explained but may be related to differences between animals in rate of VFA absorption, rate of passage to the lower digestive tract, buffering potential within the rumen, and ruminal motility.

In addition to the level of dietary roughage fed, other dietary factors such as the type of grain fed, extent of grain processing and inclusion of ionophores into the diet

affect the incidence of acidosis. Feeding behaviour can also play a significant role in acidosis development. Feeding management can influence feeding behaviour in positive or negative ways. With gradual adaptation, cattle may learn to consume high grain diets more slowly prior to introduction of high-concentrate diets in order to prevent acidosis. The number of daily feedings, amount bunk space allocated per animal and type of feed delivery (ad libitum vs. regulated or restricted feeding) are additional components of feeding management which can be manipulated to reduce acidosis. Due to the increased acidosis risk during the grain adaptation period, manipulation of feeding management and dietary factors during this time may significantly help to reduce the incidence of acidosis.

A lack of information exists in the literature regarding the incidence of acidosis during grain adaptation and how management may affect it. It is clear that abrupt dietary change from forage to concentrate can cause acidosis but beyond this little information and a lack of clarity exists regarding the effect of the number of step-up diets fed during grain adaptation on acidosis and growth performance. Further knowledge into these effects will provide feedlot managers with valuable insight upon which to base future management of grain adaptation.

3.0. EFFECT OF RAPID VS. GRADUAL GRAIN ADAPTATION ON SUBACUTE ACIDOSIS AND FEED INTAKE OF FEEDLOT CATTLE

3.1. Introduction

Adaptation of feedlot cattle from high-forage to high-concentrate diets causes marked changes in the ruminal environment, and time is required to establish a stable microbial population. The introduction of rapidly fermentable carbohydrate results in a major reduction of fibrolytic bacteria and rapid growth of amylolytic bacteria (Goad et al., 1998; Tajima et al., 2001), and a decrease in ruminal pH. Abrupt dietary change from high-forage to high-concentrate can result in acidosis (Goad et al., 1998; Coe et al., 1999) which can be classified as acute or subacute. Acute acidosis manifests as a marked illness (Owens et al., 1998) but subacute acidosis is more difficult to recognize. Decreased feed intake and performance are commonly believed to result from subacute acidosis (Koers et al., 1976; Owens et al., 1998).

To minimize problems of acidosis, cattle feeders have traditionally increased dietary concentrate in a step-by-step manner by feeding a series of diets containing sequentially increasing concentrations of grain, typically for several days at a time. Adapting cattle to grain rapidly is desirable because ADG and gain efficiency are typically enhanced when high concentrate diets are consumed. However, some acidosis prevails even with gradual adaptation to grain (Burrin and Britton, 1986; Klopfenstein et al., 2003) and more rapid rates of grain adaptation may result in increased acidosis.

Designing grain step-up programs for feedlot cattle involves balancing the opportunity for enhanced growth performance against the imposed risk of acidosis. This study was conducted to examine the impact of grain adaptation rate on the occurrence of subacute and acute acidosis by comparing the effects of rapid vs. gradual grain adaptation on rumen pH, ruminal fermentation parameters, blood chemistry, and feed intake by feedlot cattle.

3.2. Materials and Methods

3.2.1. Animals, Housing and Experimental Design

Twelve spayed, crossbred heifers were assigned randomly to two groups of six each, and used in two consecutive 20-d measurement periods, (BW ranging from 302 to 418 kg). The heifers were surgically fistulated 4 to 8 weeks prior to the study, at which time they were fitted with soft plastic 10-cm (ID) ruminal cannulae (Bar Diamond, Parma, ID). Seven days prior to the start of the trial, all heifers received a Component E-H Implant (Elanco Animal Health, Guelph, ON).

Within each group, the heifers were assigned randomly to two treatments (Table 3.1). The experiment comprised a 20-d measurement period conducted using one group of six heifers repeated immediately thereafter with the second group. During the 20-day measurement period, the six subject heifers were housed individually in 152 cm × 203 cm indoor stalls with rubber flooring, and were allowed approximately 1 h of exercise daily at 1300. All of the heifers were cared for according to guidelines of the Canadian Council on Animal Care (CCAC, 1993).

Table 3.1. Proportion of concentrate (%, DM basis) in step-up diets fed during two strategies for adaptation of heifers to barley grain-based finishing diets

	Days on which step-up diet was fed (inclusive)						
Treatment	≤0[a]	1 to 3	4 to 6	7 to 9	10 to 12	13 to 15	16 to 19
Rapid adaptation	40.0	65.0	90.0	90.0	90.0	90.0	90.0
Gradual adaptation	40.0	48.3	56.7	65.0	73.3	81.7	90.0

[a]The initial diet was fed to all heifers for 8 wk prior to commencement of measurement period.

3.2.2. Treatments and Diets

The heifers used in this study had consumed no high-grain finishing diets prior to the experiment. During the 8 weeks leading up to the start of the first measurement cycle, all 12 heifers were provided ad libitum access to a barley-silage/barley-grain/grass hay diet containing 40% concentrate (DM basis). Dietary transition from 40 to 90% concentrate (DM basis) was accomplished either over 3 d using one intermediate diet of 65% concentrate (rapid adaptation, treatment RA), or over 15 d using five intermediate diets (gradual adaptation; GA). All diets were formulated to meet NRC (1996) requirements and to contain 33 mg/kg of monensin sodium (Elanco Animal Health, Calgary, AB).

Diets were prepared fresh each day in a feed mixer. Sufficient feed to meet ad libitum consumption (at least 10% orts) was delivered daily at 1400. The concentration of dry-rolled barley was increased in the step-up diets by replacing barley silage and grass hay (Table 3.2). Barley grain for this experiment was purchased from a single source and was dry-rolled as a single batch to a processing index of 84.6% (Yang et al., 2000).

3.2.3. Feed Intake and Body Weight

The amounts of feed offered and refused were recorded daily. Samples of diets were collected on the first day of feeding and every 3 days thereafter for immediate determination of DM content and storage for chemical analysis. Samples of orts were collected and dried daily. Daily DMI for each heifer was calculated as feed DM offered minus DM refused. The DMI variation was calculated as the difference in intake between consecutive days. Samples of dietary ingredients were collected weekly and composited

Table 3.2. Ingredients and chemical compositions of the experimental step-up diets fed to heifers[a] on gradual or rapid protocols of adaptation to barley-based finishing diets

	Concentrate proportion of diet (%, DM basis)						
Item	40.0	48.3	56.7	65.0	73.3	81.7	90.0
Ingredients, % of DM							
Barley silage	45.0	41.7	38.3	35.0	26.7	18.3	10.0
Grass hay	15.0	10.0	5.0	0	0	0	0
Concentrate							
Barley grain[b]	35.0	43.3	51.7	60.0	68.3	76.7	85.0
Supplement[c]	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Chemical composition[d]							
DM, %	56.7	58.6	61.6	63.7	67.9	76.3	83.2
OM, % of DM	93.6	93.5	94.0	93.6	93.8	95.7	95.2
CP, % of DM	14.1	14.0	15.6	15.0	15.4	15.5	15.3
NDF, % of DM	38.2	37.9	32.6	32.9	31.2	31.5	31.3
ADF, % of DM	17.7	17.4	14.2	13.0	11.0	8.5	7.7

[a]On the rapid adaptation (RA) protocol, only the 40, 65 and 90% concentrate diets were fed. All diets were used in the gradual adaptation (GA) protocol (see Table 3.1).
[b]The barley grain was dry-rolled as a single lot to a processing index (PI) of 84.6%. The PI was calculated as: [(volume weight after processing/volume weight before processing) × 100%].
[c]Supplement contained: Ca, 10.9%; Na, 1.4%; Zn, 1150 ppm; Mn, 530 ppm; Cu, 290 ppm; I, 13.0 ppm; Se, 5.7 ppm; Co, 4.7 ppm; Vitamin A, 96,000 IU/kg; Vitamin D, 9500 IU/kg; Vitamin E, 630 IU/kg; and monensin sodium, 684 ppm.
[d]Values determined from analysis. All values except DM %, are expressed on a DM basis.

for analysis. The heifers were weighed at 0800 at the beginning (day 0) and end (day 19) of the experiment.

3.2.4. Ruminal pH

The ruminal pH of each heifer was monitored continuously for 23 h of each day over the entire 20-day measurement period. An industrial electrode (model PHCN-37; Omega Engineering, Stamford, CT) was inserted through the cannula into the rumen of each heifer. The electrode was enclosed in a protective shield with perforations large enough to allow ruminal fluid to percolate freely, and which prevented the electrode from contacting the ruminal epithelium. The shield was weighted to keep the electrode positioned in the ventral sac. The pH electrodes were removed for 1 h daily, from 1300 to 1400. During this time, the heifers were allowed exercise, and the electrodes were calibrated using pH 4.0 and 7.0 standards. Ruminal pH was measured every 5 seconds, and averages over 5-minute intervals were recorded by a data logger.

Ruminal pH data from the 23-h post-feeding period were summarized for each heifer as daily mean pH, maximum and minimum pH, and areas under the curves (AUC) of pH 5.2, 5.6 and 6.2 × time. Each AUC was calculated by adding the absolute value of deviations in pH below pH 5.2, 5.6, or 6.2 for each 5-min interval, and was expressed as (pH units•h). Durations of time that pH registered below the 5.6 or 5.2 thresholds were interpreted as the duration of subacute or acute acidosis, respectively, and the area between the curves and the pH thresholds as the severity of subacute or acute acidosis. Subacute ruminal acidosis was considered to have occurred when a heifer's ruminal pH remained below 5.6 for more than 12 h of a given day; acute ruminal acidosis was

considered to have occurred when ruminal pH remained below 5.2 for more than 6 h during a day of measurement.

3.2.5. Ruminal Fermentation

On days 1, 4, 7, 10, 13, 16, and 19, samples of ruminal contents were collected from each heifer prior to feeding, and 8 and 18 h after feed delivery. Ruminal contents (200 mL/site) were obtained from the reticulum, the dorsal and ventral sacs, and the feed mat, composited by animal, and placed directly into crushed ice. Once all heifers had been sampled, whole ruminal contents were immediately strained through four layers of cheesecloth. For each heifer, 5 mL of filtrate was preserved for subsequent determination of VFA and lactate by adding 1 mL of 25% (wt/vol) of metaphosphoric acid. An additional 5 mL of filtrate for determination of ammonia and glucose concentrations preserved by adding 0.8 mL 65% TCA. These samples were transferred to storage at -20°C until analyzed. Ruminal fluid osmolality was determined for each heifer within 2 h of ruminal sampling. Approximately 200 mL of rumen filtrate was placed in 250-mL centrifuge tubes and centrifuged at 13,000 × *g* for 30 min at 4°C. Osmolality of the supernatant was determined by freezing point depression using an automatic osmometer (μOsmette, Model 5004, Precision Systems Inc., Natick, MA).

3.2.6. Blood Chemistry

At 0800 on d 0, 4 and 19 (18 h after feeding), blood samples were collected from each heifer by jugular venipuncture into three 10-mL vacuum tubes (Becton Dickinson, Franklin Lakes, NJ), and transported to the Lethbridge Regional Hospital (Lethbridge,

AB) for clinical analysis of blood pH and CO_2 (both within 2 h of collection), glucose, lactate dehydrogenase, and packed cell volume, as described by Beauchemin et al. (2003).

3.2.7. Chemical Analysis

Feed DM was determined by oven drying at 55°C for 48 h. Analytical DM content of feed samples was determined by drying at 135°C for 3 h (AOAC, 1990). The methods of Van Soest et al. (1991) were used to determine NDF and ADF contents, with amylase and sodium sulfite included in the NDF procedure. Organic matter was calculated after ashing for 5 h at 500°C. Samples were reground using a ball grinder (Mixer Mill MM2000; Retsch, Haan, Germany) for determination of N. The concentration of CP (N × 6.25) in feed was quantified by flash combustion with gas chromatography and thermal conductivity detection (Carlo Erba Instruments, Milan, Italy).

Ruminal VFA were quantified using crotonic acid as the internal standard and by gas chromatography (model 5890, Hewlett Packard, Little Falls, DE) with a capillary column (30 m × 0.32 mm i.d., 1µ phase thickness, bonded PEG, supelco Nukol, Sigma-Aldrich Canada, Oakville, ON) and flame-ionization detection. Lactic acid was also determined by gas chromatography but only after derivatization with boron trifluoride-methanol as described by Supelco (1998). Ruminal ammonia was determined by the phenol-hypochlorite method (Broderick and Kang, 1980), and glucose by the ferricyanide method (Snell and Snell, 1953), both conducted on a Technicon Autoanalyzer II.

3.2.8. Statistical Analyses

Animal was considered the unit of analysis for all variables in a completely randomized design. Preliminary analysis determined that results did not differ between experimental groups and as a result group was removed from the model. For the 3 d of feeding the 65% concentrate diet, and for the first 4 d of feeding the 90% concentrate diet, daily pH variables were summarized by day, classified by treatment, and analyzed using the *t*-test procedure of SAS (SAS Institute Inc., Cary, NC). Log transformation was required to improve the normality of certain daily pH variables (AUC for pH 5.2, 5.6, and 6.2; time < pH 5.2). Data were then reported as arithmetic means. Mean hourly pH and ruminal fermentation variables from the first day of feeding 65% concentrate, and the first and fourth days of feeding 90% concentrate were also classified by treatment and analyzed using the *t*-test procedure of SAS, as were DMI and variation in DMI data from the 3 days of feeding 65% concentrate and the first 4 days of feeding 90% concentrate. The *t*-test procedure used an F-test (Steel and Torrie, 1980) for testing the equality of variance of means between treatments. A Satterthwaite (1946) approximation was used to provide an alternate *P*-value for testing means when variances differed ($P < 0.05$). On the first day of feeding the 90% concentrate diet, one of the RA heifers expelled the cannula plug, resulting in loss of ruminal contents. Ruminal data from this animal were consequently excluded from all subsequent analyses.

Variances in DMI and blood characteristics were not different between treatments, thus treatment effects were determined using the MIXED model procedure of SAS. Variation of DMI was calculated as the difference in intake between consecutive

days. Data were analyzed by day, with treatment in the model. Effects were declared significant at $P < 0.05$ and trends were discussed at $P < 0.10$.

3.3. Results and Discussion

3.3.1. Rumen pH

Mean daily pH values for cattle consuming high-concentrate barley-based diets are reported to range between 6.06 and 5.71 (Beauchemin et al., 2001; Ghorbani et al., 2001; Koenig et al., 2003). In the present study, mean daily rumen pH remained above these values until the first day of feeding 90% concentrate, when values of 5.62 and 5.70 were observed for the RA and GA heifers, respectively (Tables 3.3 and 3.4). On the first day of feeding 65% concentrate, mean rumen pH values were 5.86 (RA) and 5.97 (GA). These findings are in contrast to the mean ruminal pH as low as 5.50 and 5.56 observed by Beauchemin et al. (2003) even after 14 to 17 days of feeding a diet comprising 87% steam-rolled barley.

In grain engorgement studies in which subacute acidosis was induced, minimum pH values of 5.0 to 5.5 have been recorded on the day of grain challenge (Horn et al., 1979; Burrin and Britton, 1986; Bauer et al., 1995; Krehbiel et al., 1995; Goad et al., 1998), which are comparable to the 5.01 and 5.10 recorded for RA and GA on day 1 of feeding 90% concentrate in the present study. This suggests that the severity of the challenge was as great as has been used previously to induce subacute acidosis, but these low recorded values are more likely due to the superior ability of continuous pH monitoring to identify the true pH minima, as compared to the periodic measurements employed in the earlier studies. Continuous pH monitoring has revealed minimum pH of

Table 3.3. Effects of rapid (RA) vs. gradual adaptation (GA) protocol on daily ruminal pH variables[a] in heifers during the first three days of introduction to a barley-based step-up diet containing 65.0% concentrate

	1st day				2nd day				3rd day			
	Adaptation protocol[b]		*P* values[c]		Adaptation protocol		*P* values		Adaptation protocol		*P* values	
	Rapid	Gradual	TRT	EOV	Rapid	Gradual	TRT	EOV	Rapid	Gradual	TRT	EOV
Ruminal pH												
Mean	5.86 ± 0.42	5.97 ± 0.12	0.58	0.02	6.12 ± 0.41	6.13 ± 0.12	0.98	0.02	6.01 ± 0.43	6.16 ± 0.19	0.47	0.10
Minimum	5.29 ± 0.37	5.36 ± 0.17	0.72	0.12	5.62 ± 0.49	5.53 ± 0.14	0.68	0.02	5.48 ± 0.35	5.66 ± 0.29	0.36	0.71
Maximum	6.53 ± 0.18	6.54 ± 0.16	0.95	0.76	6.55 ± 0.27	6.59 ± 0.10	0.76	0.04	6.53 ± 0.26	6.57 ± 0.14	0.78	0.18
Area under the curve (AUC), pH•h												
6.2	9.42 ± 7.24	6.40 ± 2.45	0.37	0.03	5.03 ± 6.01	3.63 ± 1.25	0.59	0.004	6.89 ± 6.43	3.18 ± 2.40	0.23	0.05
5.6	2.43 ± 2.64	0.62 ± 0.70	0.81	0.01	0.69 ± 1.12	0.08 ± 0.18	0.24	0.001	0.98 ± 1.55	0.06 ± 0.08	0.20	<0.0001
5.2	0.28 ± 0.45	0.01 ± 0.27	0.17	<0.001	na[d]	na	na	na	na	na	na	na
Duration of pH, h/d												
<6.2	16.00 ± 6.99	16.00 ± 2.54	1.00	0.04	11.08 ± 10.05	13.58 ± 4.55	0.59	0.11	14.06 ± 9.73	11.83 ± 6.80	0.66	0.45
<5.6	7.96 ± 7.56	3.88 ± 2.91	0.26	0.06	3.35 ± 5.20	0.67 ± 0.91	0.27	0.002	5.08 ± 6.29	0.72 ± 0.84	0.15	0.0004
<5.2	2.47 ± 3.45	0.18 ± 0.44	0.20	<0.01	na	na	na	na	na	na	na	na

[a]Values shown are mean ± SD (n = 6). 'Daily' refers to a 23-h period extending from feeding time (1400 h) to 1300 the next day.

[b]All heifers were fed a diet containing 40% concentrate for 57 d. In the RA protocol, the 65% concentrate diet was introduced immediately thereafter. With GA, 48.3 and 56.7% concentrate diets were each fed for 3 d prior to 65% concentrate diet (see Table 3.1).

[c]TRT = Significance of treatment effect (rapid vs. gradual adaptation). EOV = Equality of variance; [d]na: Not available.

Table 3.4. Effects of rapid vs. gradual adaptation protocol on daily ruminal pH variables[a] in heifers during the first four days of introduction to a barley-based finishing diet containing 90% concentrate

	1st day				2nd day			
	Adaptation protocol[b]		*P* values[c]		Adaptation protocol		*P* values	
	Rapid	Gradual	TRT	EOV	Rapid	Gradual	TRT	EOV
Ruminal pH								
Mean	5.62 ± 0.30	5.70 ± 0.23	0.61	0.54	5.80 ± 0.42	5.81 ± 0.31	0.97	0.51
Minimum	5.01 ± 0.29	5.10 ± 0.16	0.53	0.22	5.16 ± 0.20	5.26 ± 0.42	0.59	0.12
Maximum	6.47 ± 0.37	6.40 ± 0.20	0.73	0.21	6.40 ± 0.60	6.51 ± 0.14	0.63	0.01
Area under the curve (AUC), pH• h								
6.2	13.96 ± 6.51	11.46 ± 4.50	0.46	0.44	10.98 ± 7.00	9.97 ± 6.06	0.80	0.76
5.6	4.27 ± 4.08	2.72 ± 1.92	0.77	0.12	2.61 ± 2.98	2.39 ± 2.04	0.89	0.42
5.2	1.11± 1.69	0.24 ± 0.33	0.62	0.003	0.28 ± 0.54	0.22 ± 0.38	0.80	0.47
Duration of pH, h/d								
<6.2	19.67 ± 2.85	19.22 ± 2.87	0.79	0.99	17.21 ± 7.19	16.65 ± 6.16	0.89	0.74
<5.6	11.99 ± 6.55	10.18 ± 5.20	0.61	0.62	8.92 ± 6.49	8.47 ± 6.67	0.91	0.95
<5.2	4.58 ± 5.28	2.18 ± 1.19	0.85	0.04	3.19 ± 5.48	2.22 ± 2.66	0.70	0.14

Continued on page 49 and 50

Table 3.4. (continued) Effects of rapid vs. gradual adaptation protocol on daily ruminal pH variables[a] in heifers during the first four days of introduction to a barley-based finishing diet containing 90% concentrate

	3rd day				4th day			
	Adaptation protocol		*P* values		Adaptation protocol		*P* values	
	Rapid	Gradual	TRT	EOV	Rapid	Gradual	TRT	EOV
Ruminal pH								
Mean	5.60 ± 0.46	5.76 ± 0.59	0.48	0.33	5.67 ± 0.29	5.69 ± 0.20	0.89	0.42
Minimum	4.95 ± 0.59	5.16 ± 0.22	0.43	0.053	5.20 ± 0.28	5.17 ± 0.13	0.86	0.12
Maximum	6.11 ± 0.56	6.36 ± 0.19	0.33	0.03	6.28 ± 0.28	6.56 ± 0.36	0.16	0.59
Area under the curve (AUC), pH• h								
6.2	14.63 ± 10.06	10.56 ± 5.56	0.41	0.22	12.23 ± 6.55	11.52 ± 4.17	0.83	0.35
5.6	5.05 ± 6.07	2.31 ± 1.97	0.33	0.03	3.11 ± 3.83	2.22 ± 1.68	0.62	0.09
5.2	1.57 ± 2.39	0.18 ± 0.24	0.21	<0.0001	0.49 ± 0.77	0.09 ± 0.13	0.25	0.001
Duration of pH, h/d								
<6.2	18.67 ± 4.41	19.39 ± 5.46	0.81	0.65	21.04 ± 2.04	19.75 ± 2.62	0.36	0.60
<5.6	10.33 ± 9.63	8.90 ± 6.04	0.76	0.33	9.08 ± 8.44	9.75 ± 5.12	0.87	0.30
<5.2	5.49 ± 8.24	1.89 ± 1.97	0.34	0.01	3.90 ± 5.86	1.21 ± 1.56	0.32	0.01

Continued on page 50

Table 3.4. (continued) Effects of rapid vs. gradual adaptation protocol on daily ruminal pH variables[a] in heifers during the first four days of introduction to a barley-based finishing diet containing 90% concentrate

[a]Values shown are mean ± SD (for RA, *n* = 5; for GA, *n* = 6). 'Daily' refers to a 23-h period extending from feeding time (1400 h) to 1300 the next day.

[b]All heifers were fed a diet containing 40% concentrate for 57 d. With rapid adaptation, a 65% concentrate diet was fed for 3 d, followed immediately by the final finishing diet (90% concentrate). Gradual adaptation included five step-up diets fed for 3 d each prior to introduction of the 90% concentrate diet (see Table 3.1).

[c]TRT = significance of treatment effect (rapid vs. gradual adaptation). EOV = equality of variance.

5.1 to 5.2 once adaptation to similar barley-based diets was complete (Ghorbani et al., 2001; Schwartzkopf-Genswein et al., 2004). In the present study, ruminal pH in the GA heifers did not fall to those levels, and in the RA group, minimum pH values were only slightly lower than those observed, on the first (pH 5.01) and third (4.95) day of feeding 90% concentrate.

Introduction of the 65% concentrate diet represented an increase of dietary concentrate from 40 to 65% for the RA heifers, compared with an increase from 56.7 to 65% for GA. Thus, grain challenge was substantially greater with RA than with GA. On the first day of feeding 65% concentrate, mean and minimum ruminal pH values were 5.86 and 5.29, respectively, for RA compared with 5.97 and 5.36 for GA. Although all daily pH variables (Table 3.3) for day 1 were numerically indicative of a lower pH for RA than for GA, the differences between treatments were not significant ($P \geq 0.17$).

In the present study, the SD of pH variables were large, sometimes approximating the measurement of the variable itself (e.g., SD of the AUC for pH 6.2, 5.6, and 5.2; duration of pH <6.2, 5.6, and 5.2; Tables 3.3 and 3.4). Such large individual animal variation may be contributing to the lack of statistical differences between the treatments. The high variance of pH variables also means that the range of potential ruminal pH extends higher and lower than with smaller variance, which may represent greater opportunity for ruminal pH of individual animals to fall into the lower and more critical levels of pH <5.6 and pH <5.2 that are indicative of subacute and acute acidosis. Thus, even when treatment means are similar, the dissimilar variances may reflect different degrees of compensation or tolerance of acidotic conditions among cattle on different adaptation regimes.

Variances of mean pH, as well as AUC and durations of pH <6.2, 5.6, and 5.2, were greater ($P < 0.05$; $P = 0.06$ for duration of pH <5.6) for RA than for GA on the first day of feeding 65% concentrate (Table 3.3). The greater variance for RA indicates that the risk of encountering acidosis was greater for individuals in group RA than for those in GA. By the definition of subacute acidosis used in this study (pH <5.6 for more than 12 h), three RA heifers encountered acidosis on day 1 of feeding 65% concentrate, compared with no heifers on the GA protocol. Given that the mean duration of pH <5.6 was only 7.96 h for the RA group, the occurrence of three cases of subacute acidosis was unexpected; however, the high SD (7.56) for duration of pH <5.6 illustrates the high variation among animals in that group. By comparison, duration of pH <5.6 was 3.88 ± 2.91 h for the GA heifers. In a similar manner, the lower SD may be indicative of their decreased risk of subacute acidosis, which is supported by the fact that subacute acidosis did not occur in any GA heifers on that day.

Over the second and third days of feeding the 65% concentrate diet, mean rumen pH in both treatment groups returned to levels above 6.0 and minimum rumen pH values (5.48 and 5.53, respectively) were higher than on the first day (Table 3.3). The variables AUC for pH 6.2 and 5.6, and duration of pH <5.6 remained numerically indicative of lower pH for RA than for GA cattle, but daily pH variables did not differ ($P \geq 0.15$) between treatments. The variance of all pH variables except duration of pH <6.2 remained larger for RA than GA ($P < 0.05$) on the second day of feeding 65% concentrate, and some (e.g., variances for AUC for pH 6.2 and 5.6, and duration of pH <5.6) for the third day as well. This indicates that the ability of individual heifers to modulate rumen pH may have been compromised on the RA protocol as compared with

GA, even 2 or 3 days after the increase in dietary concentrate. Single incidents of subacute acidosis in the RA group on the second and third days (different animals) vs. none among the GA heifers further supports this hypothesis.

Introduction of the 90% concentrate diet represented an increase directly from 65 to 90% for the heifers in treatment RA, vs. an increase from 81.7 to 90% concentrate for GA cattle. This grain challenge resulted in first-day mean and minimum pH of 5.62 and 5.01 for RA, compared with 5.70 and 5.10 for GA, respectively (Table 3.4). Similar to the 65% challenge, daily pH values on day 1 of the 90% concentrate diet were numerically indicative of lower ruminal pH with RA than with GA, but significance was not attained ($P \geq 0.46$). Whereas the increase to 65% concentrate resulted in variances of most pH variables being greater for RA than GA, the increase to 90% did not. On the first day, variances of all pH variables above pH 5.2 were large for both treatments, and subacute acidosis occurred in both treatments (three cases in RA; two cases in GA). Of note, however, is that variances for pH variables at the more threatening threshold (AUC for pH <5.2; duration of pH <5.2) were greater ($P = 0.003$ and $P = 0.04$, respectively) for RA than for GA. Among the RA heifers, mean duration of pH <5.2 was 4.58 ± 5.28 h, compared with 2.18 ± 1.19 h for GA ($P > 0.62$). With the greater variance in duration of pH <5.2 for RA compared to GA taken into account, the opportunity for acute acidosis (ruminal pH <5.2 for more than 6 h in that day) to occur in some individuals on the RA protocol was considerable, whereas the lower variance of AUC for pH <5.2 and duration of pH <5.2 observed for GA heifers suggests that their likelihood of encountering acidosis was lower. Consistent with that rationale, acute acidosis occurred in two RA

heifers on the first day of feeding the 90% concentrate diet, but was not observed in any of the GA heifers.

On the second day of feeding 90% concentrate, the variances of AUC for pH 5.2 and duration of pH <5.2 did not differ ($P > 0.14$) between treatments. Acute acidosis was observed in one animal from each treatment. The only statistically significant difference on this day was in the variance of maximum pH (RA > GA; $P = 0.01$). Maximum pH ranged from 5.81 to 7.23 among the RA heifers, compared with a range of 6.28 to 6.64 in the GA group. Variance of maximum pH also remained greater ($P = 0.03$) in RA than GA through the third day of feeding 90% concentrate. Variances in the AUC for pH 5.2 and duration of pH <5.2 were again greater ($P \leq 0.01$) with RA than with GA, and variance of AUC for pH 5.6 tended to be greater ($P \leq 0.09$), on the third and fourth days of feeding 90% concentrate diet. This was associated with one case of acute acidosis in the RA group on day 3 and two cases on day 4, compared with no cases occurring among the GA heifers on either day. Subacute acidosis was observed nine times in each of the treatment groups over the first 4 d of feeding 90% concentrate.

Post-feeding decreases in mean hourly ruminal pH on the first day of feeding 65% concentrate were similar between treatment groups (Figure 3.1). Minimum hourly pH (5.52 for RA; 5.58 for GA) occurred 8 h after feeding for both groups. This was the only point at which the hourly means fell below pH 5.6. Ruminal pH >6.0 was re-established in the GA heifers by 15 h post-feeding, compared with 18 h in the RA group; beyond that time, the GA ruminal pH continued to increase toward pre-feeding levels, whereas RA did not. Treatment effects on mean hourly pH were minor ($P \geq 0.12$) in the first day of feeding a 65% concentrate diet.

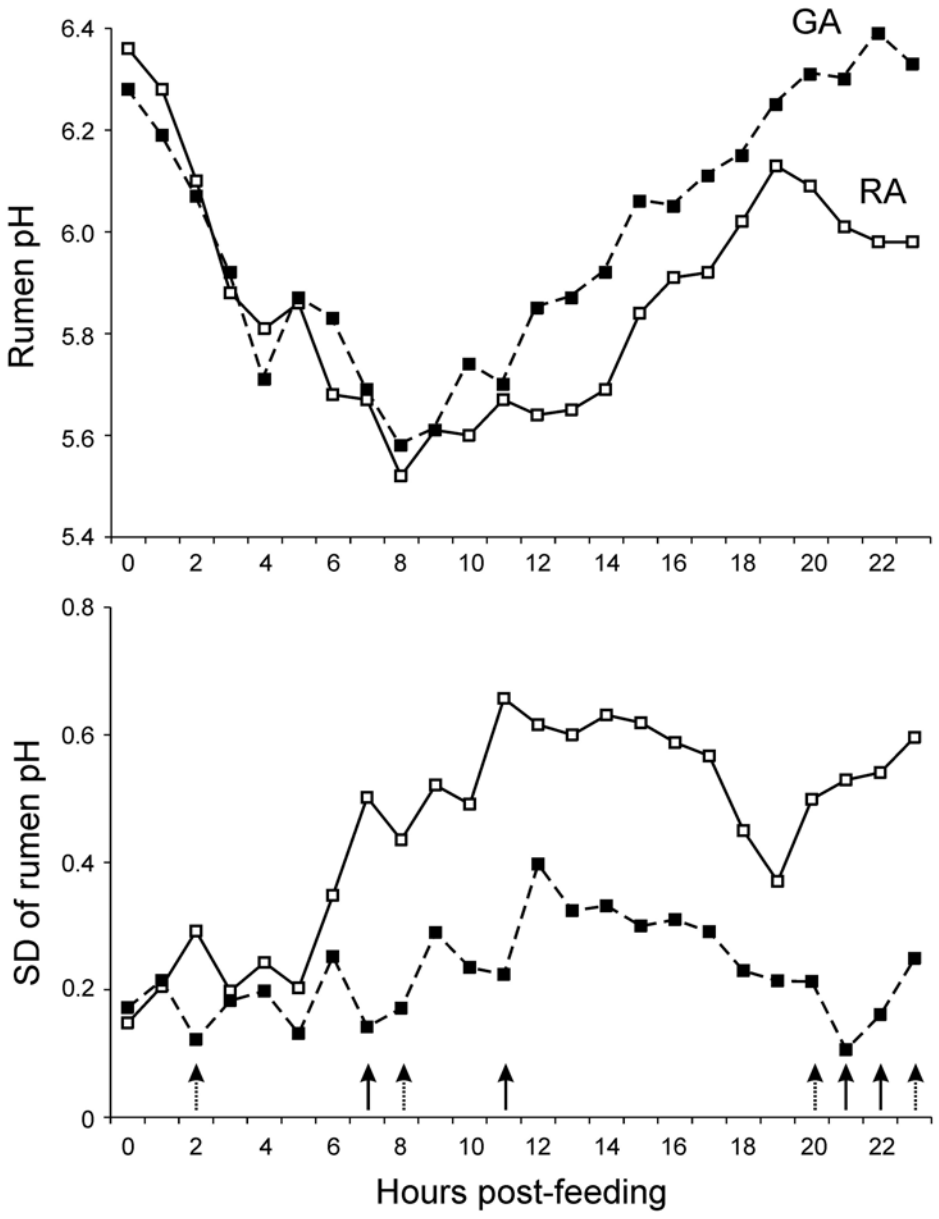

Figure 3.1. Mean hourly rumen pH and variance (expressed as standard deviation, SD) in mean hourly pH in heifers on two protocols of adaptation to high concentrate diets (n = 6) during the first day of introduction of a 65% concentrate diet. Rapid (RA) and gradual (GA) adaptation protocols are outlined in Table 3.1. Hours for which treatment effects were significant are marked with solid ($P < 0.05$) or broken ($P < 0.10$) arrows.

Variance of the hourly mean pH (depicted as SD, Figure 3.1) is an indication of the degree of uniformity of pH response among animals within a treatment group (RA, GA). Variance was initially quite similar between treatments, but from 7 h post-feeding onward, it was more pronounced ($P < 0.05$ for four of the 17 timepoints; $P < 0.10$ for two others; arrows, Figure 3.1) with RA than with GA. These observations are consistent with the summarized daily pH variables (Table 3.3) and again suggest that rapid adaptation of cattle to 65% gives rise to greater variation in ruminal pH response, as compared to gradual adaptation.

In the first 24 h after introduction of 90% concentrate, treatment effect on mean hourly pH were more evident than on d 1 of 65% (Figure 3.2). The slightly lower (5.79 vs. 6.10; $P \geq 0.12$) initial pH with GA than with RA was not unexpected, given that the GA heifers were consuming 81.7% concentrate for the 3 days prior, compared with 65% concentrate for the RA group. The ruminal pH of GA cattle declined after feeding to a minimum of 5.43 at 6 h post-feeding, but in the heifers on RA, the decline continued until 8 h post-feeding, to a minimum value of 5.34. Recovery of rumen pH to the pH 5.6 was accomplished by 11 h after feeding in the GA heifers, whereas with RA, ruminal pH remained near the minimum value for approximately 5 h, and did not rise above pH 5.6 until 16 h post-feeding. The pH of RA cattle tended to be lower ($P = 0.07$) than the pH of GA cattle at 11 and 12 h post-feeding (e.g., 5.38 ± 0.45 vs. 5.81 ± 0.26 at 11 h), which represents a delayed pH recovery that extends the exposure of RA cattle to low rumen pH, as compared with GA.

Variance of mean hourly pH of cattle fed 90% concentrate diets (Figure 3.2) tended to be less ($P < 0.10$) for RA than GA at 4, 5, 6, and 7 h post-feeding, but after 7 h

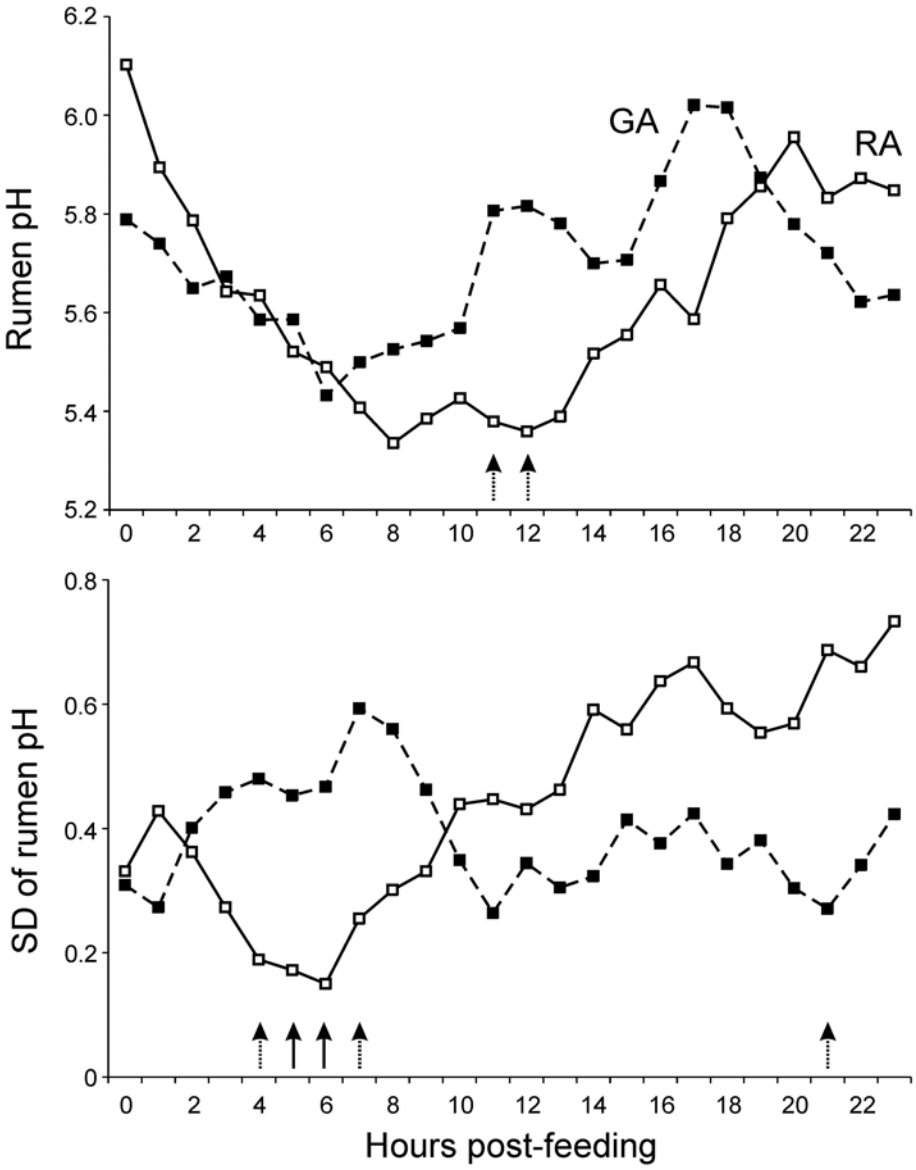

Figure 3.2. Mean hourly rumen pH and variance (expressed as standard deviation, SD) in mean hourly pH in heifers on two protocols of adaptation to high concentrate diets ($n = 6$) during the first day of introduction of a 90% concentrate diet. Rapid (RA) and gradual (GA) adaptation protocols are outlined in Table 3.1. Hours for which treatment effects were significant are marked with solid ($P < 0.05$) or broken ($P < 0.10$) arrows.

the RA variance increased steadily for the rest of the day. The sharp drop in rumen pH post-feeding together with the relatively smaller variance suggests that initially after introduction to the 90% concentrate diet, the RA heifers responded to the grain challenge with a uniform decline in rumen pH. At 7 h post-feeding, ruminal pH decline of most RA heifers began to diminish, but some continued to drop to levels associated with acute acidosis. The increasing variance in RA ruminal pH beginning at this time reflects the widening range of pH responses, which continued throughout the remainder of the day. The initial decline in rumen pH among the GA heifers was less uniform (higher variance), but beyond 7 h after feeding, when acute acidosis would have been most likely to occur, their pH variance began to decrease. Together with increasing mean hourly pH that also commenced 7 h after feeding, this demonstrates that ruminal pH recovery was more uniform and occurred earlier in the GA than the RA heifers. Increasing variance in RA and decreasing variance in GA at ≥7 h after feeding and a tendency ($P < 0.10$) toward lower ruminal pH in RA than in GA suggests that the RA protocol promoted acidosis in specific individuals following introduction of the 90% concentrate diet.

The great variation in the abilities of individual animals to cope with grain challenge that was evident in this trial has also been reported by other researchers (Dougherty et al., 1975; Brown et al., 2000). Abrupt increase from a 50% concentrate diet (dry-rolled corn) to a 95% concentrate diet (dry-rolled corn and dry-rolled wheat) resulted in substantial variation in ruminal pH among of six steers; their post-challenge ruminal pH ranged from 5.69 to 4.47 (Bauer et al., 1995). Those researchers took steps to minimize variation in ruminal pH response in a second experiment in that study by introducing a 100% concentrate diet (finely ground corn and dry rolled wheat) directly

into the rumen of cannulated animals. Other attempts to minimize variation in ruminal pH response have combined this technique with withholding feed from cattle prior to the grain challenge (Coe et al., 1999; Brown et al., 2000). Using these methods appears to have increased the occurrence of acidosis and also appears to have resulted in more uniform rumen pH response among animals within a treatment, which improves the opportunity to identify statistically significant differences. This increased frequency and uniformity of acidosis has helped with achieving research objectives in a number of studies, but by minimizing variation, this method has inadvertently contributed to a lack of recognition of the level of pH variation that occurs under conventional feeding conditions and also how management strategies may be affecting this biological phenomenon. Examination of the variance of pH variables measured under rapid vs. gradual grain adaptation strategies in the present study is an effective indicator of individual animal variation, and has revealed clearly that rapid grain adaptation results in a more variable pH response than gradual adaptation. The greater variance observed with RA compared with GA corresponded with increased incidence of subacute acidosis following introduction of 65% concentrate and of acute acidosis after step-up directly to 90% concentrate.

The demonstration that the variance increases with the severity of challenge represents a useful approach to assessing the potential of acidotic conditions developing in cattle under varying feeding management practices. Even though the present experiment only had six animals per treatment, the degree of challenge was clearly reflected in the degree of variance equality.

3.3.2. Rumen Fermentation

Ruminal lactate concentration has been reported to exceed 50 m*M* during incidents of acute acidosis during which rumen pH was between 3.9 and 4.5 (Dunlop, 1972; Nagaraja et al., 1985). However, during cases of perceived subacute acidosis, lactic acid may not accumulate (Horn et al., 1979; Beauchemin et al., 2003) and when it does, concentrations seldom exceed 10 m*M* (Harmon et al., 1985; Burrin and Britton., 1986; Goad et al., 1998; Hristov et al., 2001; Ghorbani et al., 2002). When Coe et al. (1999) adapted steers from a 100% roughage diet to 100% concentrate (65% cracked corn:25% cracked wheat, DM basis) in 6 days using two intermediate diets, measured mean ruminal lactate concentration did not exceed 0.4 m*M*. Similarly, ruminal lactate concentrations in the present study were generally very low, often below the 1 m*M* level of detection (data not shown). Exceptions did occur; however, on the first day of feeding 90% concentrate, elevated lactic acid concentrations were measured in two RA heifers (22.3 and 6.5 m*M*) and one GA heifer (34.6 m*M*) at 8 h after feeding. This observation was not unexpected in the RA group, having been reported previously for rapidly adapted cattle (Bauer et al., 1995), but its occurrence in the GA heifer was surprising and indicates that even with gradual adaptation to grain, ruminal lactate can accumulate in some individuals. At the time of the elevated lactate concentrations, ruminal pH values recorded for the affected heifers were 5.45 and 5.44 (RA) and 5.20 (GA). In two of the three individuals (i.e., the RA heifer with 6.5 m*M* lactate and the GA heifer), minimum ruminal pH had been logged at 7 h (pH 5.24) and 7.5 h (pH 5.00) post-feeding, respectively, and as it continued to increase beyond the 8-h sampling, acute acidosis was averted. In contrast, ruminal pH of the RA heifer with 22.3 m*M* lactate continued to decline from 5.45 at 8 h

to a minimum of 4.53 at approximately 18 h after feeding. Quite possibly, continued accumulation of lactate contributed to this prolonged decrease in ruminal pH.

Lactate acid accumulation occurs when abrupt introduction of rapidly fermentable carbohydrate stimulates proliferation of the rapidly growing lactic acid-producing bacterium S*treptococcus bovis* so that it exceeds the growth rate of lactic acid utilizing bacteria (Russell and Hino, 1985; Dawson and Allison, 1988). As a result of the imbalance between production and utilization, an accumulation of lactic acid occurs, but often only in specific individuals. The factors (microbial or otherwise) that may predispose certain animals to lactic acid accumulation remain largely unknown.

Heifers from both treatment groups in the present study were observed with no detectable ruminal lactate, but high ruminal VFA concentrations and consequently, ruminal pH that was even lower than heifers with high lactate concentrations. These results are consistent with total acid load, not lactate alone, being responsible for low pH (Britton and Stock, 1987). In this study, low rumen pH appeared to be associated primarily with accumulated VFA, as ruminal VFA concentrations followed a pattern inverse to that observed for pH.

In general, VFA concentrations in this study were low prior to feeding, highest at 8 h post-feeding and intermediate at 18 h post-feeding. On the first days of feeding 65 or 90% concentrate, total ruminal VFA concentrations (Table 3.5) were substantially higher than the values of 97 to 120 m*M* reported previously for cattle consuming a similar barley-grain based finishing diet (Krause et al., 1998; Ghorbani et al., 2002; Beauchemin et al., 2003; Koenig et al., 2003), although in studies designed to simulate acidosis, total

Table 3.5. Effects of rapid vs. gradual adaptation protocol on ruminal fermentation variables (mean ± SD) measured 0, 8 and 18 h after introduction of 65% and 90% concentrate diets, and on the fourth day of feeding the 90% diet

Time after feeding	0 h		8 h		18 h	
Adaptation protocol	Rapid	Gradual	Rapid	Gradual	Rapid	Gradual
1st day at 65% concentrate						
Total VFA, m*M*	103.3 ± 8.5	109.4 ± 11.1	162.6 ± 22.4	162.7 ± 9.9	137.4 ± 22.9	134.2 ±15.3
Acetate, molar %	60.7 ± 4.0	58.6 ± 2.3	56.0 ± 5.3	52.1 ± 3.2	54.9 ± 5.7	49.4 ± 6.9
Propionate, molar %	26.0 ± 4.9	24.6 ± 4.5	30.3 ± 8.6	30.1 ± 5.5	30.3 ± 8.9	30.8 ± 6.4
Butyrate, molar %	9.2 ± 1.8	11.3 ± 3.9	9.8 ± 2.9	12.8 ± 4.7	10.2 ± 4.3[c]	14.7 ± 3.1[b]
Acetate:propionate	2.5 ± 0.7	2.5 ± 0.5	2.1 ± 0.9	1.8 ± 0.4	2.0 ± 0.8	1.7 ± 0.6
Ammonia, m*M*	2.1 ± 1.4	2.5 ± 2.7	5.2 ± 3.9	6.8 ± 3.7	7.7 ± 5.5	5.6 ± 2.9
Osmolality, mOsm/kg	300 ± 11	309 ± 11	357 ± 40	357 ± 16	342 ± 31	333 ± 22
1st day at 90% concentrate						
Total VFA, m*M*	113.3 ± 19.3	121.4 ± 17.8	161.4 ± 21.8	148.6 ± 40.3	126.8 ± 23.8	115.4 ± 11.0
Acetate, molar %	56.4 ± 6.8	41.6 ± 3.7	49.8 ± 5.7	45.9 ± 8.5	45.8 ± 4.4	45.9 ± 5.5
Propionate, molar %	25.0 ± 7.4	28.7 ± 6.7	33.8 ± 8.5	32.9 ± 9.7	36.7 ± 7.6	34.4 ± 5.1
Butyrate, molar %	13.3 ± 3.5	14.0 ± 2.8	12.7 ± 3.8	16.2 ± 3.6	12.8 ± 6.4	13.0 ± 1.7
Acetate:propionate	2.5 ± 0.9	1.9 ± 0.6	1.6 ± 0.7	1.7 ± 1.2	1.3 ± 0.3	1.4 ± 0.4
Ammonia, m*M*	3.3 ± 3.1	4.3 ± 2.6	4.6 ± 1.9	7.4 ± 3.5	6.5 ± 4.7	10.4 ± 3.8
Osmolality, mOsm/kg	308 ± 6[c]	333 ± 14[b]	366 ± 31	378 ± 37	333 ± 19	332 ± 42

Continued on page 63

Table 3.5 Continued. Effects of rapid vs. gradual adaptation protocol on ruminal fermentation variables (mean ± SD) measured 0, 8 and 18 h after introduction of 65% and 90% concentrate diets, and on the fourth day of feeding the 90% diet

Time after feeding	0 h		8 h		18 h	
Adaptation protocol	Rapid	Gradual	Rapid	Gradual	Rapid	Gradual
4th day at 90% concentrate						
Total VFA, m*M*	132.8 ± 19.5	120.0 ± 30.4	140.4 ± 25.3	137.1 ± 37.4	121.4 ± 9.2	114.1 ± 16.7
Acetate, molar %	45.2 ± 6.7	48.1 ± 10.0	47.1 ± 8.8	46.8 ± 9.8	44.2 ± 7.0	47.6 ± 6.4
Propionate, molar %	39.9 ± 7.6	35.7 ± 11.3	33.2 ± 8.1	36.7 ± 10.4	38.1 ± 9.3	35.1 ± 8.5
Butyrate, molar %	10.1 ± 6.6	11.4 ± 4.3	13.9 ± 6.9	11.1 ± 4.2	10.2 ± 8.0	10.7 ± 3.1
Acetate:propionate	1.2 ± 0.3	1.7 ± 1.2	1.6 ± 0.7	1.5 ± 0.9	1.2 ± 0.3	1.5 ± 0.7
Ammonia, m*M*	2.8 ± 3.3	5.2 ± 3.6	3.6 ± 3.9[e]	7.5 ± 3.1[d]	6.3 ± 2.8[e]	10.6 ± 4.5[d]
Osmolality, mOsm/kg	323 ± 18	335 ± 18	340 ± 16	355 ±33	328 ± 10	339 ± 43

[a]Rapid adaptation entailed transition from 40% to 90% concentrate diets in 3 d using one intermediate diet (65% concentrate); with gradual adaptation, the step-up from 40% to 90% concentrate was accomplished over 15 d using five levels of concentrate (see Table 3.1).

[b,c]Within a row and sampling time, values followed by different letters differ ($P < 0.05$).

[d,e]Within a row and sampling time, values followed by different letters differ ($P < 0.10$).

VFA concentrations of 130 to 140 m*M* have been reported (Burrin and Britton, 1986; Bauer et al., 1995).

Fermentation acids accumulate within the rumen when production exceeds absorption across the rumen wall or passage from the rumen through the omasal orifice (Allen, 1997). It is unlikely that VFA production in this study would greatly exceed that reported in other trials in which similar diets were fed, thus the relatively high VFA concentrations must have resulted from a lower rate of VFA absorption or passage of VFA from the rumen. The absorptive capacity of the rumen increases during adaptation to high grain diets via increased number and length of rumen papillae, which is reported to require 8 weeks for completion (Dirksen et al., 1985). Thus, incomplete adaptation of rumen papillae during the 20-day experimental period in the present study likely contributed to a slower rate of VFA absorption, relative to production, leading to VFA accumulation. The resulting lower ruminal pH would increase the protonated form of the acids, which are more readily absorbed across the rumen wall into the bloodstream, but the high VFA concentrations recorded indicate that this potential enhancement of absorption was insufficient to offset accumulation.

Few treatment effects were observed on the other rumen fermentation variables measured. Adaptation protocol did not affect individual VFA concentrations or acetate:propionate ratios (Table 3.5) measured 0, 8 and 18 h after feeding on the first day of feeding 65% concentrate, or on first or fourth days of feeding 90%. Free glucose concentrations measured 8 h after introduction of 65 or 90% concentrate diets were also similar across treatments (data not shown) and remained very low throughout the study with the exception of 4.4 m*M* glucose measured in the RA heifer that registered 22.3 m*M*

ruminal lactate (day 1 of 90% concentrate). Osmolality of ruminal fluid differed with treatment (GA > RA; $P < 0.05$) only once, in the pre-feeding (0 h) sample collected on the first day of feeding 90% concentrate. Ruminal ammonia concentrations were similar across treatments, except on the fourth day of feeding 90% concentrate, when they tended ($P < 0.10$) to be lower in RA than in GA heifers at 8 and 18 h after feeding.

3.3.3. Blood Variables

The pH of blood samples collected on days 0, 4 and 19 did not differ among days or between treatments (Table 3.6) indicating that neither RA nor GA heifers were experiencing metabolic acidosis as a result of the grain challenge. Under normal conditions, blood pH is highly regulated and rarely fluctuates, because it is saturated with bicarbonate (Owens et al., 1998). However, during acute acidosis, excess acid production may exhaust the buffering capacity of the bicarbonate and blood pH decreases. When metabolic acidosis occurs, reduced levels of bicarbonate in blood result in increased concentrations of CO_2 (Owens et al., 1998). Depressed blood CO_2 levels are therefore taken to represent a lower risk of metabolic acidosis (Brown et al., 2000). In the present study, CO_2 concentrations were unaffected by sampling day or adaptation protocol, which is consistent with similar pH in indicating that the risk of metabolic acidosis was similar for both treatment groups. Lactate dehydrogenase concentration in blood tends to increase during acidosis as a result of a greater need to metabolize lactic acid (Owens et al., 1998), and may therefore also be considered an indicator of metabolic acidosis risk. Heifers on the RA protocol exhibited higher LDH concentration than the GA heifers (4,524 vs. 3,750 units/L; $P < 0.05$) on day 4, but consumption of different diets on that

Table 3.6. Effects of rapid vs. gradual adaptation[a] to a high concentrate diet on blood chemistry of heifers during a 20-d transition from 40% to 90% concentrate diets

Measurement	Sampling day	Rapid adaptation (RA)	Gradual adaptation (GA)	SE	*P* value
Blood pH	0	7.41	7.38	0.01	0.17
	4	7.38	7.40	0.01	0.19
	19	7.38	7.37	0.02	0.77
pCO_2, mEq/L	0	49	50	3	0.77
	4	48	48	1	0.91
	19	47	45	1	0.32
Packed cell volume, %	0	30	31	1	0.61
	4	29	32	1	0.16
	19	31	31	1	0.65
Glucose, g/L	0	1.02	1.08	0.04	0.30
	4	1.05	1.06	0.05	0.85
	19	1.02	1.00	0.04	0.73
Lactate dehydrogenase, U/L	0	4629	4118	265	0.20
	4	4524	3750	234	0.04
	19	3991	3839	294	0.71

[a] Rapid adaptation entailed transition from 40% to 90% concentrate diets in 3 d using one intermediate diet; on the gradual adaptation protocol, step-up from 40% to 90% concentrate was accomplished over 15 d using five levels of concentrate (see Table 3.1).Day 4 was the first day that the 90% concentrate diet was fed to the RA heifers. Day 19 was the fourth day of 90% concentrate for the GA heifers (16th day for RA).

day (90% concentrate for RA vs. 56.7% for GA) makes it difficult to interpret this difference. Packed cell volume and blood glucose were not affected by treatment, which is also indicative that on the days of blood sampling, metabolic acidosis was not occurring in either treatment group (Owens et al., 1998; Brown et al., 2000). Blood was not collected from the GA heifers on their first day of consuming 90% concentrate diets (day 16) as it was for the RA heifers (d 4), but it is unlikely that metabolic acidosis would have arisen on day 1 of 90% concentrate in the more subtle GA protocol, given that it was not indicated among the RA heifers.

3.3.4. Feed Intake

Overall DMI averaged 9.55 kg/d over the 20-day experimental period in the present study, and did not differ between treatments. Depressed feed intake is commonly observed during adaptation to high grain diets (Tremere et al., 1968; Hironaka, 1969; Fulton et al., 1979b), and feed intake depression is often accentuated when digestive disturbance is severe (Owens et al., 1998). In the present study, DMI on each of the days of feeding identical diets (i.e., the 3 days of feeding 65% concentrate and the initial 4 days of feeding 90% concentrate) were similar between treatments (Table 3.7). However, DMI intake by individual animals was not consistent over time, and widely ranging DMI was observed among individuals on both adaptation protocols. For example, on the second day of feeding 90% concentrate diets, DMI ranged from 0.59 to 11.2 kg for RA heifers, and from 5.35 to 12.7 kg for those in the GA group.

Treatment × day interactive effects on intake were not observed ($P < 0.10$) in this study, but overall intake was affected by day of feeding of a particular diet (Table 3.8). Of note

Table 3.7. Effect of rapid vs. gradual adaptation[a] on DMI and DMI variation of heifers in the first three or four days following introduction of diets containing 65% and 90% concentrate

Item	Rapid adaptation	Gradual adaptation	*P* value	
			TRT[b]	Equality of variance
65% concentrate				
DMI, kg				
First day	10.17 ± 1.37	11.02 ± 1.78	0.37	0.58
Second day	9.31 ± 1.77	10.25 ± 1.76	0.38	0.99
Third day	8.85 ± 1.96	10.25 ± 2.65	0.32	0.52
DMI variation, kg[c]				
First day	1.16 ± 0.66	1.45 ± 0.96	0.55	0.42
Second day	0.96 ± 1.21	1.08 ± 1.07	0.87	0.79
Third day	0.74 ± 0.50	0.77 ± 0.82	0.94	0.31
90% concentrate				
DMI, kg				
First day	10.23 ± 2.12	9.84 ± 1.70	0.73	0.64
Second day	8.76 ± 4.18	8.00 ± 1.05	0.71	0.31
Third day	9.21 ± 1.96	9.04 ± 2.44	0.90	0.64
Fourth day	9.15 ± 1.49	8.81 ± 1.55	0.70	0.93
DMI variation, kg				
First day	2.07 ± 1.08	1.21 ± 1.30	0.23	0.71
Second day	2.04 ± 3.46	1.84 ± 1.05	0.90	0.02
Third day	1.87 ± 2.14	1.92 ± 1.34	0.96	0.33
Fourth day	1.00 ± 0.70	1.18 ± 0.53	0.65	0.54

[a] Rapid adaptation entailed transition from 40% to 90% concentrate diets in 3 d using one intermediate diet; with gradual adaptation, step-up from 40% to 90% concentrate was accomplished over 15 d using five levels of concentrate (see Table 3.1).
[b] TRT: effect of adaptation protocol (rapid vs. gradual adaptation).
[c] DMI variation = difference between DMI of the current and previous day.

Table 3.8. Dry matter intake and variance in DMI following introduction of diets containing 65% or 90% concentrate to feedlot heifers on two protocols of grain adaptation[c]

Diet	Measurement	Day of feeding diet				SE[d]
		First	Second	Third	Fourth	
65% concentrate diet						
	DMI, kg/d	10.59[a]	9.78[b]	9.55[b]	NA[e]	0.55
	DMI variation, kg[f]	1.30	1.02	0.75	NA	0.33
90% concentrate diet						
	DMI, kg/d	10.03[a]	8.38[b]	9.13[ab]	8.98[ab]	0.69
	DMI variation, kg	1.64	1.94	1.89	1.09	0.73

[a,b]Within a row, means lacking a common superscript letter differ ($P < 0.05$).

[c]Adaptation protocols are described in Table 3.1. No treatment effects or treatment × day interactive effects were observed ($P > 0.10$); therefore, values shown are averaged across treatments.

[d]SE: Standard error ($n = 12$).

[e]NA = not applicable (the 65% diet was fed for only 3 d during the step-up protocol).

[f]DMI variation = difference between DMI of the current and previous day.

is that DMI was lower ($P < 0.05$) on the second and third days of feeding 65% and the second day of 90% concentrate than on the days those diets were first introduced. Intake by all but one of the heifers (RA and GA) in the study declined on day 2 as compared to day 1 of feeding 90% concentrate, but most were relatively small decreases. The most severe drop in DMI from first to second day of 90% concentrate was 8.99 kg recorded for a heifer on RA protocol; surprisingly, the second largest DMI reduction was in the GA group (4.29 kg). In RA and GA, the heifers with the lowest ruminal pH on day 1 registered the greatest reduction in DMI on day 2. This is consistent with a highly positive correlation between minimum rumen pH on the day of grain insult and feed intake of the following day reported by Brown et al. (2002).

Some day-to-day fluctuation in intake is normal for cattle confined in metabolism stalls and fed to appetite (Schwartzkopf-Genswein et al., 2004), but increased variation in feed intake has been identified as an indicator of subacute acidosis (Fulton et al., 1979b; Britton and Stock, 1987; Bauer et al., 1995; Stock et al., 1995). In the present study, DMI variation between consecutive days was not affected by treatment (or day) on any of the days the 65 or 90% concentrate diets were fed, but on day 2 of feeding 90% concentrate, the variance (range) of the day-to-day variations was greater ($P < 0.05$) with RA than with GA. This indicates that individual heifers in the RA group may not have regulated their feed intake as uniformly as did those in the GA group following the increase to 90% concentrate.

3.3.5. Individual animal concentrate intake and rumen pH

Previous research on acidosis and efforts at diagnosis has been hampered by the low incidence of this condition within populations of cattle (Galyean, 2001). Feeding management strategies prescribed by nutritionists and feedlot managers are often developed with the intent of preventing acute acidosis, which typically means they are designed with greater consideration of the individuals prone to acidosis than of the majority of the low-susceptibility animals within the pen. Data from the present study demonstrates that considerable variation exists in the ability of individual animals to cope with grain challenge. Hence, some consideration of individual animal response is essential for continued improvement of feeding strategies for feedlot cattle.

Mean hourly ruminal pH and daily intake of concentrate over the 20-day measurement periods were plotted for each individual heifer, and assessed for the desirability of the relationship between these variables. The perceived most desirable (i.e., consistent circadian periodicity of pH, steadily increasing DM intake) and, conversely, the least desirable relationships, as well as treatment means are presented in Figure 3.3. From both treatment groups, the heifers with the most desirable profiles exhibited exceptionally effective moderation of ruminal pH during high concentrate intake. Introducing the 90% concentrate diet, however, did constitute a nutritional challenge to the heifers, decreasing their ruminal pH and slightly depressing intake of concentrate on day 2, 3 and 4. Nonetheless, DMI by these heifers remained high and in spite of the availability of additional fermentable substrate, acidosis did not occur.

The least desirable profiles from both RA and GA heifers were characterized by lower intake and lower, more variable rumen pH. One of the RA heifers (Figure 3.3)

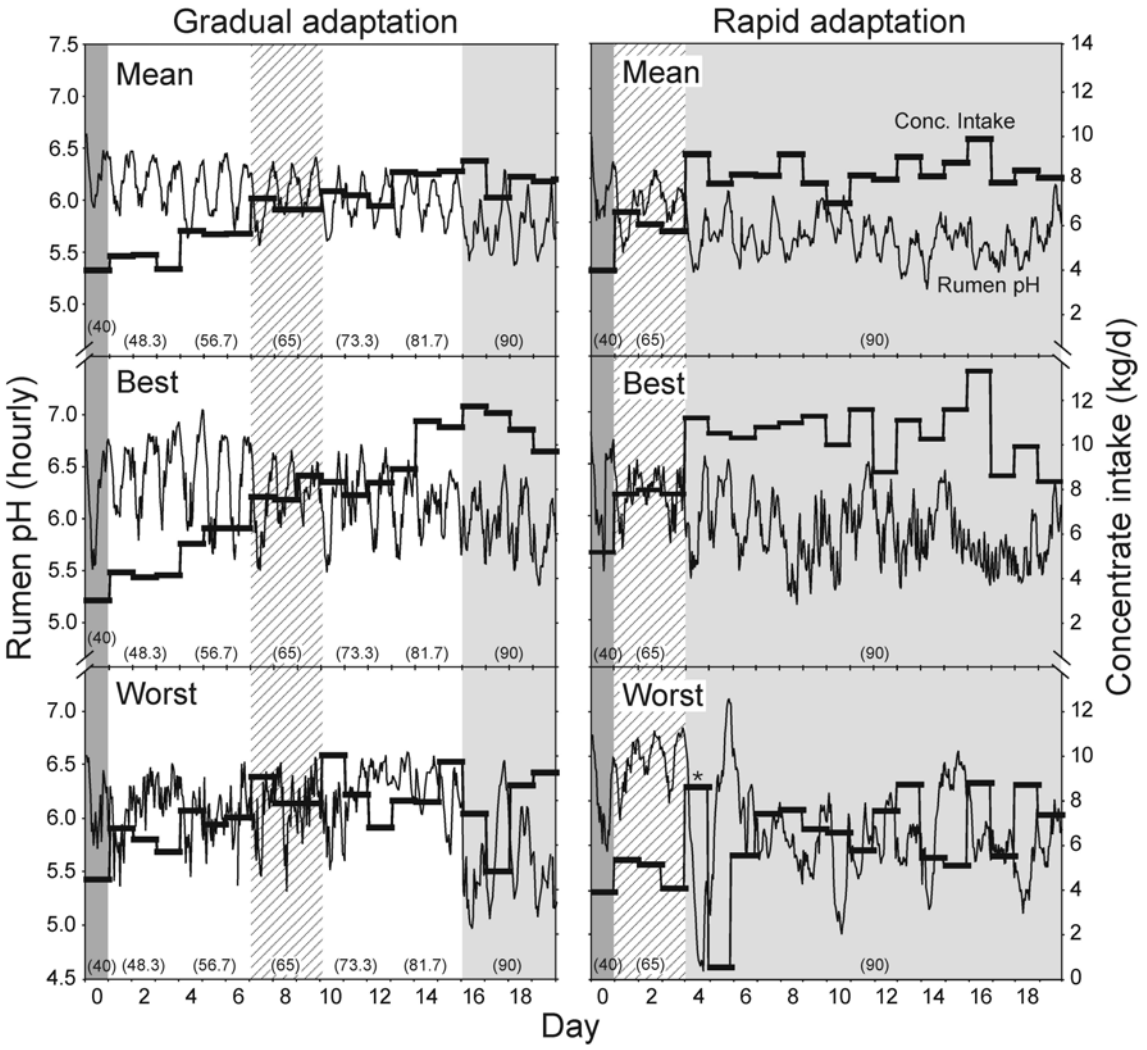

Figure 3.3. Mean hourly ruminal pH (thin line) and daily intake of dietary concentrate (thick bars) by heifers during gradual (five intermediate diets; 15 d) or rapid (one intermediate diet; 3 d) adaptation from a 40 to a 90% concentrate diet. Profiles shown are: means for treatment groups (n = 6; top panels), those of the individual heifers in each treatment group deemed to have exhibited the most desirable (best; middle panels) and least desirable (worst; bottom panels) moderation of ruminal pH and maintenance of DMI over the 20-d adaptation periods. Values in parentheses are the percentages of concentrate in each of the step-up diets (DM basis). On the day marked with an asterisk (*), the ruminal lactate concentration in the RA heifer was 22.3 m*M* (measured 8 h after feeding).

exhibited markedly increased feed intake on the first day that 90% concentrate was fed after having registered rather low intake of the 65% diet. Even though the ruminal pH had been relatively high, this substantially increased intake of concentrate resulted in a drastic decline of pH and onset of acute acidosis (minimum pH = 4.53; AUC for pH 5.2 = 4.31, duration of pH <5.2 = 10.08). Feed intake on the third and fourth days of 90% concentrate was improved, but remained very low in comparison to the mean intake for RA heifers, suggesting prolonged effects of the day-2 disturbance on pattern of intake.

None of the individuals in the GA group responded to grain increase as drastically as did this RA heifer, but neither was the transition to 90% concentrate entirely smooth. In the heifer exhibiting the least desirable profile, rumen pH was often low, and concentrate intake was quite variable. For this heifer, each increase in concentrate intake resulted in lower rumen pH on that day, and depressed DMI for several days thereafter. Introduction of the 90% concentrate diet resulted in a major pH decline during the first day, and low intake the day after. Intake on the third and fourth days of feeding 90% concentrate returned to levels above the treatment average, suggesting that the effects of adaptation were less severe for this heifer than for the RA heifer whose intake remained low. These results indicate that some animals experience acidosis even when additional step-up diets are incorporated into the adaptation protocol (i.e., a gradual step-up program is not likely to completely eliminate the occurrence of acidosis). Rather, the incidence (total number) and the severity of individual cases of acidosis are likely to be reduced in comparison with more abrupt step-up programs.

It is difficult to explain why some heifers managed uneventful transition to finishing diets while others, even in the same treatment group, became acidotic. It is

important to recognize that acidosis does not result solely from high intake of rapidly fermentable. In this trial, heifers who maintained a healthy rumen pH often consumed more rapidly fermentable carbohydrate on the day of grain challenge than did other heifers that became acidotic. Factors such as rate of intake and selectivity at the bunk may have played a role in acidosis development, but are not likely to have evoked such large differences in response. It seems more likely that differences in ruminal pH arose from differing rates of VFA absorption, differing rates of fluid passage out of the rumen, differences in saliva production (buffering capacity), and/or differences in VFA metabolism among animals, but identification of the specific metabolic factors that predispose certain individuals to acidosis is beyond the scope of this study. Thus, although the present observations document the range of susceptibility that exists among individual cattle, preventing acidosis in commercial feedlots must remain linked to management strategies based on outcomes for the most acidosis-prone individuals, rather than on means for the pen.

3.4. Implications

In this study, few ruminal pH or fermentation variables were affected by rapid vs. gradual adaptation to a high concentrate diet, but the variance of many pH variables was far greater for rapidly adapted than for gradually adapted heifers. This increased variance represents increased opportunity for acidosis to occur in some individuals and suggests that this may be a useful approach to assess the effect of feeding management techniques on acidosis. The current objective of step-up programs in commercial feedlots is to minimize or prevent cases of acidosis, which requires that management of grain

adaptation be tailored to the most susceptible individuals. In that approach, consideration of individual animal response is essential. Although data suggest that most cattle can successfully handle a rapid rate of grain adaptation, minimizing acidosis in the most susceptible individuals requires reducing the pace of grain adaptation for the entire group. Defining metabolic factors that give rise to acidosis in high-risk individuals could provide a key to developing new preventative strategies for subacute and acute acidosis.

4.0. EFFECT OF THE NUMBER OF STEP-UP DIETS FED DURING ADAPTATION TO A BARLEY-GRAIN BASED DIET ON BEHAVIOUR AND GROWTH PERFORMANCE OF FEEDLOT CATTLE

4.1. Introduction

It is known that during the introduction of feedlot cattle to high concentrate finishing diets, the risk for acidosis is high. Acidosis is undesirable because it can result in reduced growth performance of cattle (Stock et al., 1990; Larson et al., 1993). To help prevent acidosis, increases in dietary grain content are typically accomplished by feeding a series of step-up diets which contain an increasing concentration of grain. Enhanced ADG and efficiency of gain are typically obtained when cattle consume high concentrate diets. When designing a step-up program feedlot managers attempt to balance the risk for acidosis with the opportunity for enhanced growth performance. However, the rate at which dietary concentrate can be increased without causing significant acidosis is not yet clear. As a result, step-up programs vary widely among feedlots.

The incidence of acidosis, occurring among cattle fed in large groups, is difficult to assess. Because of this difficulty, little direct research has been conducted to determine the extent to which grain adaptation may be shortened without causing significant acidosis. Use of radio frequency technology now provides the ability for measurement of individual animal feeding behaviour among group fed cattle. Feeding behaviour, measured using this technology, has been successfully used to identify morbid feedlot cattle (Sowell et al., 1999; Buhman et al., 2000). Measurement of feeding behaviour may

also provide some insight into the development and incidence of acidosis among group fed cattle. Assessment of feeding behaviour during grain adaptation may contribute to defining the optimal number of diets that are required to adapt cattle to high-grain diets. The objectives of this study were to determine the effect of the number of step-up diets fed during adaptation of cattle to a barley-based finishing diet on feeding behaviour and growth performance.

4.2. Materials and Methods

4.2.1. Animals Feed and Housing

This study involved 120 crossbred (British × British) heifers (366.9 ± 23.8 kg BW) which were delivered from a single source (McIntyre Ranch, Magrath, Alberta). Upon arrival at the research feedlot, the heifers were provided access to a diet containing 40% concentrate (35% dry-rolled barley, 5% supplement), 15% grass hay and 45% barley silage (DM basis). Heifers were processed on the third day after arrival. At processing, all heifers received a Component E-H implant (Elanco, Guelph, ON) and were vaccinated for IBR, BVD, PI3, BRSV and pasteurella haemolytica toxoid (Pyramid 4 + Presponse; Wyeth Animal Health, Guelph, ON). They also received a seven-way clostridial bacterin-toxoid (Vision 7®; Intervet Canada Ltd., Whitby, ON) and received Ivomec (Merial Canada, Baie d'Urfe, QC) for broad-spectrum parasite control. In addition, a radio frequency transponder (Allflex USA, Dallas Ft. Worth, TX) was placed in the ear of each animal to enable electronic monitoring of individual feeding behaviour.

Cattle were individually weighed on both the third and fourth day after arrival at the feedlot. On the fourth day heifers were blocked by weight and assigned to one of

three pens measuring 40.2 × 27.4 m which were equipped with the GrowSafe® System as previously described by Basarab et al. (2003). This system allowed measurement of individual animal feeding behaviour and consisted of five individual stalls allowing individual animal access to feed from any stall. After placement in the GrowSafe® pens, heifers were provided 10 days for habituation to their new surroundings, before step-up diets were introduced.

Treatments consisted of (1) dietary transition from 40 to 90% concentrate (DM basis) in 3 days using three levels of dietary concentrate (rapid adaptation; RA), (2) in 9 days using five levels of dietary concentrate (moderate adaptation; MA) or (3) in 15 days using seven levels of dietary concentrate (gradual adaptation; GA) (Table 4.1). Adaptive diets consisted of an increasing concentration of dry-rolled barley grain replacing barley silage and grass hay. After grain step-up was complete heifers remained on the 90% concentrate diet for the remainder of this study. The composition of each diet is presented in Table 4.2 and all diets were formulated to meet NRC (1996) requirements. Feed was delivered 2 to 3 times daily to meet ad libitum consumption. The initial feeding occurred at approximately 0800, a second feeding occurred at approximately 1300 and a third feeding was provided in the evening when needed to maintain ad-libitum intake (10% feed refusal).

4.2.2. Diet Analysis

Diet samples were collected on the first day of feeding each diet to each treatment. After cattle were consuming the final 90% concentrate diet, samples of that diet were collected on a weekly basis. Feed DM was determined by oven drying at 55°C

Table 4.1. Percent concentrate (DM basis) in diets fed to heifers during adaptation to a barley-based finishing diet containing 90% concentrate

Item	Day of trial						
Treatment	0[a]	1-3	4-6	7-9	10-12	13-15	16-19
Rapid adaptation (RA)	40.0	65.0	90.0	90.0	90.0	90.0	90.0
Moderate adaptation (MA)	40.0	52.5	65.0	77.5	90.0	90.0	90.0
Gradual adaptation (GA)	40.0	48.3	56.7	65.0	73.3	81.7	90.0

[a] Initial 40% diet was fed to all cattle for 14 d prior to the introduction of step-up diets.

Table 4.2. Ingredients and chemical compositions of the experimental step-up diets fed to heifers[a] during adaptation to a barley-based finishing diet

	Concentrate proportion in diet (%, DM basis)								
Item	40	48.3	52.5	56.7	65	73.3	77.5	81.7	90
Ingredient, % of DM									
Barley silage	45.0	41.7	40.0	38.3	35.0	26.7	22.5	18.3	10.0
Grass hay	15.0	10.0	7.5	5.0	0	0	0	0	0
Barley grain	35.0	43.3	47.5	51.7	60.0	68.3	72.5	76.7	85.0
Supplement[b]	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Chemical Composition[c]									
DM	57.0	58.6	57.7	61.5	58.1	67.9	71.4	71.7	80.3
OM, % of DM	92.3	92.5	92.6	94.0	94.2	94.5	93.8	95.0	94.7
CP, % of DM	13.5	13.3	13.3	13.9	13.2	14.2	14.0	14.5	14.3
NDF, % of DM	38.7	37.2	38.2	35.6	35.5	31.3	32.9	31.9	31.5
ADF, % of DM	19.3	18.0	18.9	15.3	14.8	11.0	12.5	10.1	8.9

[a]For rapid adaptation (RA), only the 40, 65 and 90% concentrate diets were fed. For moderate adaptation (MA), only the 40, 52.5, 65, 77.5 and 90% concentrate diets were fed. For gradual adaptation (GA) diets containing 40, 48.3, 56.7, 65.0, 73.3, 81.7 and 90% concentrate were fed (see Table 4.1).

[b]Supplement contained: Ca, 10.9%; Na, 1.4%; Zn, 1150 ppm; Mn, 530 ppm; Cu, 290 ppm; I, 13.0 ppm; Se, 5.7 ppm; Co, 4.7 ppm; Vitamin A, 96,000 IU/kg; Vitamin D, 9500 IU/kg; Vitamin E, 630 IU/kg; and monensin sodium, 684 ppm.

[c]Values determined from analysis.

for 48 h. Subsequently, samples of the 40, 65 and 90% concentrate diets from all treatments were composited for analysis. All other diets were specific to individual treatments and for them analysis was completed individually. Analytical DM content of feed samples was determined by drying at 135ºC for 3 h (AOAC, 1990). The NDF and ADF contents were determined by the methods described by Van Soest et al. (1991), with amylase and sodium sulfite used in the NDF procedure. Samples were reground using a ball grinder (Mixer Mill MM2000, Retsch, Haan, Germany) for determination of N. The concentration of CP (N × 6.25) in feed was quantified by flash combustion with gas chromatography and thermal conductivity detection (Carlo Erba Instruments, Milan, Italy).

4.2.3. Feeding Behaviour and ADG

Frequency of visits and duration of cattle attendance at the feed bunk were recorded using the feed bunk monitoring system. Data were collected for 24 h each day for each individual heifer throughout the 69 day trial beginning 10 days prior to introduction of step-up diets. The system was checked every 2 days throughout the trial to ensure that all cells within the mat were operational (Schwartzkopf-Genswein et al., 2001). Frequent system monitoring indicated that there were no inoperable cells during the trial. All occasions when animals were removed from their pens were recorded and data for that day and animal were discarded from the behavioural data set. In order to isolate distinct feeding events, a visit was defined as attendance at the feed bunk after an absence of at least 5 min; a return within 5 min was considered to be continuous attendance. The definition of a visit was based on research carried out by Gibb and McAllister (1999) and

Sowell et al. (1998). Measures of feeding behaviour reported in this study include daily bunk attendance (DBA) measured from 0800 to 0759 h daily; 6 h bunk attendance (6HBA) (i.e., the bunk attendance of each heifer measured during 6 h intervals); and maximum intermeal interval (MII) (i.e., the maximum interval of time spent by each individual animal without approaching the feed bunk during the 36 h following feeding). Individual feed intake data collected using the GrowSafe® system was determined to be invalid (due to widespread equipment failure) and was discarded from research results.

Initial cattle weights were recorded for individual heifers on day 1 and 2 which were 10 and 11 days prior to the start of grain adaptation. Subsequent animal weights were recorded for each heifer following grain step-up on day 34 and 35 and again at the end of the trial on day 69 and 70.

4.2.4. Statistical Analysis

Feeding behaviour data were analyzed as a completely randomized design using the GLM procedure in SAS (SAS Institute Inc., 1999). Individual heifers were considered to be the unit of analysis for all measured variables. Results were analyzed by diet and day for the effect of treatment on DBA, visits to the bunk and MII. Results were analyzed by diet and period for the effect of treatment on 6HBA. The mixed model procedure in SAS (SAS Institute Inc., 1999) was used for analysis of ADG. The model included the fixed effect of treatment and period. Treatment effects were declared significant at $P < 0.05$.

4.3. Results

4.3.1. Feeding Behaviour

On the day prior to the introduction of step up diets, while all cattle were still consuming the 40% concentrate diet, DBA was similar ($P > 0.05$) between all treatments. For day 1, 2 and 3 after the introduction of 65% dietary concentrate, DBA was less ($P < 0.05$) for RA heifers than for MA heifers (Table 4.3). The DBA of RA heifers was also less ($P < 0.05$) than DBA of GA heifers on day 2 and 3 after the introduction of the 65% concentrate diet but DBA did not differ ($P > 0.05$) on d 1 of feeding that diet. The DBA of GA heifers was also less ($P < 0.05$) than DBA of MA heifers on d 1 and 2 of feeding the 65% concentrate diet. However, on day 3 of feeding 65% concentrate DBA was similar ($P > 0.05$) between MA and GA heifers. For days 1 to 6 of feeding 90% concentrate DBA did not differ ($P > 0.05$) between any treatment except on day 4. On day 4 DBA of RA heifers was less ($P < 0.05$) than DBA of MA heifers.

The number of visits to the feed bunk was also affected by the number of step-up diets fed. On the final day of feeding 40% concentrate (the day prior to the introduction of step-up diets), the number of bunk visits was similar ($P \geq 0.60$) for all treatments (Table 4.3). However, on day 1 following the introduction of 65% concentrate the number of bunk visits was greater ($P < 0.05$) for MA heifers than for RA or GA heifers and on day 2 the number of bunk visits was greater ($P < 0.05$) for both MA and GA heifers than for RA heifers. Surprisingly, with the step to 90% concentrate the opposite occurred and the number of bunk visits was greater ($P < 0.05$) for RA than for MA or GA cattle on day 1 of feeding that diet. On day 2 of 90% concentrate, the number of bunk visits for RA heifers began to decline but bunk visits for RA heifers still remained greater

Table 4.3. Effect of the number of step-up diets on daily bunk attendance and daily bunk visits of heifers during adaptation to 65 and 90% concentrate.

	Treatment		
Item	Rapid Adaptation[f]	Moderate Adaptation[g]	Gradual Adaptation[h]
Daily Bunk Attendance[d]			
40% Concentrate[i]	131.9 ± 8.13	123.6 ± 9.79	109.6 ± 6.38
65% Concentrate			
Day 1	96.8 ± 5.54[b]	132.4 ± 8.56[a]	107.3 ± 6.83[b]
Day 2	80.9 ± 6.70[c]	128.6 ± 5.79[a]	104.3 ± 6.68[b]
Day 3	90.4 ± 7.72[b]	121.7 ± 5.81[a]	114.6 ± 6.43[a]
90% Concentrate			
Day 1	105.1 ± 5.62	106.9 ± 6.24	97.0 ± 5.88
Day 2	102.1 ± 6.95	97.4 ± 5.38	104.2 ± 5.81
Day 3	95.2 ± 4.60	106.3 ± 6.56	107.4 ± 5.06
Day 4	92.2 ± 4.20[b]	110.9 ± 5.10[a]	106.9 ± 6.24[a]
Day 5	100.6 ± 4.47	112.4 ± 6.34	106.5 ± 4.70
Day 6	101.9 ± 5.05	108.3 ± 4.43	114.9 ± 6.41
Visits[e]			
40% Concentrate[i]	10.7 ± 0.56	10.2 ± 0.53	11.1 ± 0.67
65% Concentrate			
Day 1	9.6 ± 0.56[b]	13.3 ± 0.72[a]	10.9 ± 0.61[b]
Day 2	7.8 ± 0.67[b]	12.5 ± 0.53[a]	11.0 ± 0.63[a]
Day 3	10.4 ± 0.88	10.4[2] ± 0.44	11.6 ± 0.55
90% Concentrate			
Day 1	13.4 ± 0.66[a]	10.2 ± 0.55[b]	11.1 ± 0.53[b]
Day 2	12.7 ± 0.74[a]	10.7 ± 0.51[b]	11.7 ± 0.65[a, b]
Day 3	10.8 ± 0.57	11.2 ± 0.53	10.4 ± 0.41
Day 4	11.0 ± 0.53	10.8 ± 0.45	10.6 ± 0.56
Day 5	11.7 ± 0.61	11.1 ± 0.44	10.9 ± 0.59
Day 6	11.8 ± 0.67	10.8 ± 0.48	10.8 ± 0.53

[a,b,c]Within a row, values without a common superscript differ ($P < 0.05$)

[d] Minutes per day

[e]Attendance at the feed bunk after an absence of at least 5 min

[f]Transitioned from 40 to 90% dietary concentrate in 3 d using 3 levels of dietary concentrate.

[g]Transitioned from 40 to 90% dietary concentrate in 9 d using 5 levels of dietary concentrate.

[h]Transitioned from 40 to 90% dietary concentrate in 15 d using 7 levels of dietary concentrate.

[i]Reported for the day prior to start of grain step-up.

($P < 0.05$) than for MA heifers. On days 3 to 6 of feeding 90% concentrate, the number of bunk visits remained between 10 and 11 visits/d and was similar ($P > 0.05$) for all treatments.

The 6HBA for the 36 hours following the introduction of the 65 and 90% concentrate diets is shown in Table 4.4. During the first (0800 to 1400) and third (2000 to 0200) intervals, following the step-up to 65% concentrate, 6HBA did not differ ($P > 0.05$) between treatments. However, during the second (1400 to 2000), fourth (0200 to 0800), fifth (0800 to 1400) and sixth (1400 to 2000) intervals RA heifers exhibited a shorter ($P < 0.05$) 6HBA than MA heifers. The RA heifers also exhibited a shorter ($P < 0.05$) 6HBA than GA heifers during the fourth and fifth intervals. The GA heifers had a shorter ($P < 0.05$) 6HBA than MA heifers during the second, fourth and sixth intervals. During the fifth interval 6HBA of GA and MA were similar ($P > 0.05$). Following the introduction of 90% concentrate, 6HBA was similar ($P >0.05$) between all treatments during each of the 6 h intervals except for period 4 (0200 to 0800) during which 6HBA was greater ($P < 0.05$) for MA and GA heifers than for RA heifers.

The effect of adaptation method on MII is shown in Table 4.5. Following feeding, on day 1 of 65% concentrate, MII was greatest ($P < 0.05$) for RA heifers (13.7 h), lower ($P < 0.05$) for GA heifers (10.4 h) and lowest ($P < 0.05$) for MA (6.6 h) heifers (Table 4.5). On day 2 MII of RA heifers (12.4 h) remained greater ($P < 0.05$) than MII of MA (8.3h) or GA (7.7 h) heifers. On day 3 MII of RA heifers declined from the previous level and thus did not differ ($P >0.05$) from either of the other treatments. Following the increase to 90% concentrate MII did not differ ($P > 0.05$) between treatments on any day (1 to 8) except for day 6. On day 6 MII was greater ($P < 0.05$) for RA compared to MA or GA.

Table 4.4. Effect of the number of step-up diets fed during grain adaptation on six hour bunk attendance[d] of feedlot cattle

	Treatment		
Interval[e]	Rapid Adaptation[f]	Moderate Adaptation[g]	Gradual Adaptation[h]
65% Concentrate			
0 – 6 h	42.1 ± 3.48	41.1 ± 2.95	40.3 ± 3.35
6 – 12 h	5.3 ± 1.25[b]	24.0 ± 3.46[a]	5.0 ± 1.25[b]
12 – 18 h	34.9 ± 4.06	35.5 ± 3.45	34.3 ± 2.80
18 – 24 h	9.8 ± 2.21[c]	32.4 ± 2.88[a]	22.4 ± 3.19[b]
24 – 30 h	27.9 ± 3.32[b]	43.7 ± 2.95[a]	39.7 ± 3.61[a]
30 - 36 h	5.6 ± 1.51[b]	14.5 ± 2.26[a]	3.3 ± 1.08[a]
90% Concentrate			
0 – 6 h	35.8 ± 3.28	34.2 ± 2.44	30.4 ± 3.14
6 – 12 h	18.2 ± 2.45	12.5 ± 2.26	13.6 ± 2.06
12 – 18 h	32.9 ± 2.50	35.6 ± 3.36	32.2 ± 2.73
18 – 24 h	15.2 ± 2.32[b]	24.2 ± 2.89[a]	23.5 ± 2.60[a]
24 – 30 h	35.8 ± 3.80	30.5 ± 2.67	35.5 ± 2.28
30 - 36 h	15.9 ± 2.28	11.9 ± 2.15	11.2 ± 1.70

[a,b,c]Within a row, values without a common superscript differ ($P < 0.05$).

[d] bunk attendance (minutes) of heifers measured during 6 h intervals

[e]Beginning at 8:00 AM following introduction of the 65 or 90% concentrate diet

[f]Transitioned from 40 to 90% dietary concentrate in 3 d using 3 levels of dietary concentrate.

[f] Transitioned from 40 to 90% dietary concentrate in 9 d using 5 levels of dietary concentrate.

[g] Transitioned from 40 to 90% dietary concentrate in 15 d using 7 levels of dietary concentrate.

Table 4.5. Effect of the number of step-up rations fed during grain adaptation on duration of maximum intermeal interval[d] of feedlot cattle

	Treatment		
Item	Rapid Adaptation[e]	Moderate Adaptation[f]	Gradual Adaptation[g]
40% Concentrate			
Day 0[h]	9.1 ± 0.51	10.0 ± 0.48	10.7 ± 0.78
65% Concentrate			
Day 1	13.7 ± 0.78[a]	6.6 ± 0.31[c]	10.4 ± 0.76[b]
Day 2	12.4 ± 1.17[a]	8.3 ± 0.46[b]	7.7 ± 0.47[b]
Day 3	8.2 ± 0.69	8.3 ± 0.61	9.1 ± 0.40
90% Concentrate			
Day 1	8.7 ± 0.77	8.7 ± 0.64	7.5 ± 0.35
Day 2	9.0 ± 0.71	8.3 ± 0.45	8.7 ± 0.48
Day 3	8.5 ± 0.64	7.1 ± 0.24	7.8 ± 0.37
Day 4	6.7 ± 0.39	7.5 ± 0.38	7.5 ± 0.35
Day 5	8.1 ± 0.61	7.8 ± 0.35	8.1 ± 0.59
Day 6	8.5 ± 0.42[a]	7.0 ± 0.29[b]	7.2 ± 0.31[b]
Day 7	8.0 ± 0.42	7.6 ± 0.40	8.6 ± 0.52
Day 8	8.0 ± 0.41	7.8 ± 0.43	8.7 ± 0.56

[a,b,c] Within a row, values without a common superscript differ ($P < 0.05$).
[d] Maximum interval of time (h) spent without approaching the feedbunk during the 36 h following the first daily feeding (08:00).
[e]Transitioned from 40 to 90% dietary concentrate in 3 d using 3 levels of dietary concentrate.
[f] Transitioned from 40 to 90% dietary concentrate in 9 d using 5 levels of dietary concentrate.
[g]Transitioned from 40 to 90% dietary concentrate in 15 d using 7 levels of dietary concentrate.
[h]Measured on day before grain adaptation began.

4.3.2. Average Daily Gain

Over the first 34 days of this trial, during grain adaptation, ADG of RA heifers was less ($P = 0.01$) than ADG of MA heifers (Table 4.6). The ADG of GA heifers was intermediate and did not differ ($P \geq 0.17$) from ADG of either RA or MA heifers. For days 35 to 69 of the trial ADG of RA became greater ($P = 0.003$) than ADG of MA cattle and ADG of GA cattle was again intermediate and did not differ ($P \geq 0.06$) between RA and MA. Over the entire 69 days of this study ADG did not differ between any treatment ($P \geq 0.41$).

4.4. Discussion

4.4.1. Feeding Behaviour

For cattle consuming high concentrate finishing diets, typical durations of DBA which have been reported in the literature include 112.1 ± 1.6 min (Schwartzkopf-Genswein et al., 2002) and 111.4 – 122.1 min (Parsons et al., 2004). Although somewhat variable, the durations of DBA reported in this study (Table 4.3) are similar to these previously reported durations. The lower DBA of RA heifers compared to typically higher DBA of MA and GA heifers (Table 4.3) for day 1, 2 and 3 of feeding 65% concentrate, in this study, might easily be incorrectly interpreted to represent a reduction in feed intake for rapid adapted heifers. Low or reduced feed intake of feedlot cattle is often used as an indication of acidosis. Brown et al. (2000) reported a high correlation (r = 0.843) between the lowest daily rumen pH of cattle and feed intake on the following day. Fulton et al. (1979a) also reported that feed intake can be inhibited by low rumen

Table 4.6. Effect of the number of step-up diets fed during grain adaptation on ADG of feedlot cattle

Item	Rapid Adaptation[c]	Moderate Adaptation[d]	Gradual Adaptation[e]	SE
Heifers, *n*	40	40	40	
Daily gain[f], kg				
Day 1 - 34[g]	1.28[b]	1.51[a]	1.39[ab]	0.063
Day 35 – 69	2.03[a]	1.76[b]	1.86[ab]	0.064
Day 1 – 69	1.69	1.64	1.63	0.046

[a,b] Within a row values without a common superscript differ ($P < 0.05$).

[c]Transitioned from 40 to 90% dietary concentrate in 3 d using 3 levels of dietary concentrate.

[d] Transitioned from 40 to 90% dietary concentrate in 9 d using 5 levels of dietary concentrate.

[e] Transitioned from 40 to 90% dietary concentrate in 15 d using 7 levels of dietary concentrate.

[f]ADG was calculated based on live animal weights measured on two consecutive days.

[g] Introduction of step-up diets began on d 12.

pH. If shorter DBA of RA heifers caused a DMI reduction, the correlation between rumen pH and intake (Brown et al., 2000) would suggest that rumen pH was somewhat lower for RA compared to MA and GA cattle following the introduction of 65% dietary concentrate. However, it is very important to recognize that rate of feed intake can be variable and the correlation between bunk attendance and feed intake is often weak (Gibb et al., 1998; Schwartzkopf-Genswein et al., 2002). Despite lower DBA for RA heifers than for MA or GA heifers on day 1 and 2 of feeding the 65% concentrate diet, average DMI of RA heifers (Table 4.7) does not appear to have been lower than average DMI of MA heifers on either of these days. This appears to be the result of changes in eating rate. Variable eating rates were also apparent with the step to 90% concentrate. Although the DBA of RA heifers did not differ ($P > 0.05$) from MA and GA for day 1 to 3 of feeding 90% concentrate (Table 4.3), average DMI of RA heifers did appear to be somewhat reduced on those days (Table 4.7).

Bauer et al. (1995) reported that during grain adaptation, as the level of dietary concentrate increased, daily patterns of DMI changed from consumption of large meals to consumption of smaller more frequent meals. Klopfenstein et al. (2003) also concluded that during grain adaptation cattle learn to consume meals more slowly in order to help prevent acidosis. In contrast, bunk attendance and the number of bunk visits in this study did not generally appear to increase as higher concentrate diets were fed (Table 4.3). However, on day 1 of feeding 90% concentrate, RA heifers did visit the bunk more frequently than MA or GA cattle. The cause for increased visits might be speculated to represent an attempt by RA heifers to distribute DMI over more visits. On the other

Table 4.7. Observations of average DMI[a] (kg) of heifers following introduction to diets containing 65 and 90% concentrate (DM basis)

Item	Rapid Adaptation	Moderate Adaptation	Gradual Adaptation
65% Concentrate			
Day 1	9.0	7.3	8.9
Day 2	9.4	7.8	9.1
Day 3	7.0	8.7	8.3
90% Concentrate			
Day 1	7.8	10.8	10.6
Day 2	7.1	9.6	9.0
Day 3	8.2	8.7	9.5
Day 4	8.5	9.3	9.9
Day 5	8.5	9.2	10.4
Day 6	8.7	9.4	10.3
Day 7	9.0	9.7	10.3
Day 8	8.8	10.1	10.2

[a] $n = 1$.

[b]Transitioned from 40 to 90% dietary concentrate in 3 d using 3 levels of dietary concentrate.

[c] Transitioned from 40 to 90% dietary concentrate in 9 d using 5 levels of dietary concentrate.

[d] Transitioned from 40 to 90% dietary concentrate in 15 d using 7 levels of dietary concentrate.

hand, increased visits to the feed bunk may have been due to greater curiosity and contemplation of intake but reluctance of cattle to actually consume as much feed following effects of a potentially high initial intake of the 90% concentrate diet.

Measurement of 6HBA was completed to provide a measure of within-day changes in feeding behaviour as they occurred over the first six 6 h periods following the introduction of the 65 and 90% concentrate diets. Following the increase to 65% concentrate, similar 6HBA for all treatments during the first 6 h interval suggests that initially, cattle in all treatments readily consumed the 65% diet. However, reduced attendance for RA compared to MA during intervals 2, 4, 5 and 6 suggests that the abrupt grain increase may have caused an increased level of discomfort for RA cattle. Following the increase to 65% concentrate the 6HBA for GA heifers was intermediate between RA and MA for most 6 h intervals. However, from 24 to 30 h when 6HBA of RA was low, the 6HBA for MA remained high. Reduced attendance for RA but not for GA during this time interval indicates an increased level of discomfort for RA compared to MA and GA cattle. It is also important to recognize that 6HBA for RA heifers from 24 to 30 h (34.9 ± 4.06) appeared to be reduced compared to their attendance (42.1 ± 3.48 min) during the 0 to 6 h period on the previous day. This seems to indicate that some level of feed aversion was encountered for RA heifers on day 2 of feeding 65% concentrate; however, this reduction did not appear to occur for MA or GA cattle.

The step to 90% dietary concentrate resulted in a more uniform 6HBA response between treatments. However, even with this step, a shorter ($P < 0.05$) 6HBA for RA compared to MA and GA from 18 to 24 h post-feeding may provide further indication of increased discomfort for RA cattle.

Of all feeding behaviours measured in this study MII may provide the most meaningful indication of digestive discomfort for feedlot cattle. The association between MII and digestive discomfort is based on the premise that cattle with acute acidosis often go "off feed" (Tremere et al., 1968; Brown et al., 2000; Klopfenstein et al., 2003) and thus will not attend the feed bunk for an extended period of time. The greater MII for RA heifers than for MA or GA heifers on both day 1 and 2 of feeding 65% concentrate strongly suggests that an increased level of discomfort was encountered by RA cattle. The significance of this difference in MII is emphasized by the observation that 18 out of 40 heifers in the RA treatment exhibited a MII of ≥ 14 h on day 1 after introduction of the 65% diet. For the same 36 h period, 0 MA heifers and only 7 GA heifers exhibited a MII of ≥ 14 h. Similar MII for all treatments following feeding on day 3 of the 65% concentrate diet suggests that any additional discomfort causing an extended MII for RA heifers must have subsided by 50 h post-feeding of the 65% diet.

Surprisingly MII did not differ between treatments on any day following the increase to 90% concentrate except for day 6 (Table 4.6). Even on day 6 where MII was greater for RA than for MA, the duration of MII for RA (8.5 h) didn't appear to be unusually long. Although MII did not differ between treatments for the first 36 h following introduction of 90% concentrate there were 6 heifers in the RA treatment which exhibited a MII of ≥ 14 h. The MII of these six RA heifers were 24.0, 20.8, 17.4, 15.2, 14.7 and 14.0 h. There were only 2 heifers in MA (duration of 22.4 and 14.5 h) and no heifers in GA which exhibited a MII of ≥ 14 h during the same 36 h period. Although MII did not differ between treatments on day 1 of feeding 90% concentrate, based on the

number of heifers with a MII of > 14 h in each treatment, the risk for some individual animals to go off feed appears to be greater with rapid grain adaptation.

For RA heifers, MII appeared to be greater on day 1 and 2 following the increase to 65% concentrate than on any other day for any other treatment following the increase to 90% concentrate. The greater MII occurring for RA heifers on day 1 and 2 of the 65% diet may suggest that the degree of digestive discomfort for cattle is equal if not greater during the transition from 40 to 65% concentrate than during the transition from 65 to 90% concentrate. When cereal grains are fed, different microbial species predominate in the ruminal ecosystem than when forage is fed (Dehority and Orpin, 1988). If greater discomfort did occur for RA cattle following the step to 65% concentrate, it may reflect a greater amount of microbial change occurring during the grain increase to 65% as compared to the final increase to 90% concentrate. However, on day 2 following the increase to 90% concentrate, a number of heifers in the RA treatment exhibited diarrhea (visual observation) whereas little diarrhea was observed for RA cattle following the step to 65% concentrate. Diarrhea occurring during grain adaptation is commonly interpreted by feedlot managers and nutritionists to indicate acidosis has occurred. It is somewhat surprising that even though diarrhea was visually observed in a number of RA heifers on day 2 of feeding 90% concentrate, MII was not increased on that day.

4.4.2. Average Daily Gain

A reduced ADG of RA compared to MA heifers during the first 34 days of this study appears to have resulted from the increased rate of grain step-up for RA heifers. If the improved ADG of MA compared to RA cattle was due to reduced digestive

disturbance, it might be expected that ADG of GA cattle would also improve. Instead the ADG of GA cattle was intermediate and did not differ from either RA or MA cattle during the first 34 days. Rather than resulting from increased digestive disturbance, the intermediate ADG of GA cattle is likely due to the lower energy content in the diet of GA heifers during their extended adaptation period compared to higher energy content in the diet of MA and RA heifers. However, because feed intake is not known this is only speculation.

When acidosis is severe, the effects of a single bout of acidosis can result in long term performance reductions (Brent, 1976; Klopfenstein et al., 2003). It is important to recognize that although the ADG of RA heifers was initially less than for MA heifers, initially low ADG did not cause long term performance reductions. In fact during days 35 to 69, ADG for RA cattle exceeded the ADG of MA cattle. Over this period ADG of GA cattle was again intermediate. Cumulative ADG for the first 70 days of this study, which did not differ between any treatments, clearly demonstrates that long term performance was not inhibited by the method of grain adaptation for any treatment group. Thus, any degree of acidosis which may have been encountered during this study was not severe enough to result in any long term reduction of ADG.

4.5. Implications

The number of step-up diets fed during the dietary transition from forage to concentrate can affect feeding behaviour of feedlot cattle. Although digestive discomfort appeared to be increased with rapid adaptation, moderate adaptation did not appear to result in greater discomfort than the gradual adaptation method. Effects of the number of

step-up diets on feeding behaviour appear to be greater following the step to 65% concentrate than following the step to 90% concentrate. However, rapid step-up to a 90% concentrate diet did result in negative feeding behaviours for some individual heifers. The results of this study indicate that during the initial period of grain adaptation ADG of rapidly adapted cattle may be negatively impacted. However, results from this study also demonstrate that despite any initial ADG reduction, long term ADG was not affected by the number of step-up diets fed.

5.0. SUMMARY AND CONCLUSIONS

In North America, feedlot cattle are typically finished on diets which consist primarily of grain. These diets are desirable because enhanced average daily gain, efficiency of gain and superior carcass quality are generally obtained when high-grain diets are consumed. In addition, delivery of grain to the feed bunk is efficient and North American consumers have developed a taste preference for grain fed beef. Although feeding of high grain diets is desirable, feeding a high level of grain can result in acidosis in feedlot cattle. It is well recognized that as the level of grain intake increases, the risk for acidosis also increases. Reductions in feed intake and growth performance of cattle caused by acidosis are of primary concern to feedlot managers and nutritionists. The opportunity for acidosis to occur is particularly high during the initial introduction of cattle to high concentrate diets. Abrupt dietary change from forage to concentrate can result in acidosis; therefore, cattle feeders have traditionally increased dietary concentrate in a step-by-step manner by feeding a series of sequential diets containing an increasing grain concentration. Effects of the number of step-up diets on acidosis and growth performance are not clear. Determination of the extent to which the period of grain adaptation might be shortened without causing significant acidosis is of significant interest. The objective of this research was to determine effects of the number of step-up diets fed during grain adaptation on feeding behaviour, rumen pH and fermentation (acidosis), and growth performance of feedlot cattle.

Two trials were completed. First, a metabolism trial investigated the effects of rapid (dietary transition from 40 to 90% concentrate in 3 days using 3 levels of concentrate) vs. gradual (dietary transition from 40 to 90% concentrate in 15 days using 7

levels of concentrate) adaptation to a high concentrate diet on rumen pH and fermentation, blood acid base status and dry matter intake of feedlot cattle.

In the metabolism trial means of daily ruminal pH variables did not differ as a result of rapid vs. gradual adaptation to the 65 or 90% diet. However, the variance of many pH variables was far greater for rapid adapted than for gradual adapted heifers on day 1 following the increase to 65% concentrate. The greater variance of pH variables observed with rapid adaptation indicated that the risk of encountering acidosis for rapid adapted individuals was greater than the risk of acidosis for gradual adapted individuals. Accordingly, on day 1 of feeding 65% concentrate, subclinical acidosis (pH < 5.6 for > 12 h/day) did occur in 3 of the 6 rapid adapted heifers and did not occur in any of the gradual adapted heifers. With the increase to 90% concentrate, variance of pH variables for gradual adapted heifers increased and variance of pH variables above pH 5.2 did not differ between adaptation methods. However, on day 1 of feeding the 90% diet, the variance of the area and time of pH < 5.2 was much greater for rapid than gradual adapted heifers. The increased variance of the area and time of pH < 5.2 was a result of acute acidosis (pH < 5.2 for > 6 h/day) which occurred in two rapidly adapted individuals but which did not occur for any gradually adapted individuals.

Mean hourly pH for the first 24 h following introduction of the 65% diet also did not differ between treatments. However, the variability between individual animal pH responses was once again greater with rapid adaptation. Initially with the increase to 90% concentrate, the rumen pH of all rapidly adapted heifers declined quite uniformly. For rapid adapted heifers, rumen pH decline was accelerated and rumen pH dropped to a lower level than for gradual adapted heifers. For some rapid adapted heifers, pH decline

appeared to be easily reversed and rumen pH did not fall into deleterious ranges whereas rumen pH of other rapid adapted heifers continued to decline and resulted in acute acidosis.

Low rumen pH in the metabolism trial was primarily due to high accumulation of VFA. Similar to rumen pH variables, ruminal VFA concentrations and osmolality did not differ between rapid and gradual adapted heifers. Concentrations of lactic acid (once thought to be primarily responsible for acidosis) were generally < 1m*M* and did not play a significant role in development of acidosis for most heifers. However lactic acid accumulation was involved in the development of acute acidosis for one heifer on day 1 of feeding 90% concentrate. In addition, acidosis was confined primarily to the rumen and did not result in systemic acidosis.

In the metabolism trial, a high amount of variation in the ability of individual animals to cope with grain challenge was evident. In addition, variability of ruminal pH response between animals was clearly increased with rapid adaptation in comparison to gradual adaptation. If the effect of increased variance of rumen pH variables is ignored, based on a lack of statistical difference between means, it might be concluded that acidosis was similar regardless of the adaptation method and rapid adaptation might be recommended. However, it is important that the increased variability of animal response with rapid adaptation be considered. In commercial feedlots, the current objective of step-up programs is to prevent or at least minimize occurrence of acidosis for all individuals. If acidosis is to be prevented management of grain adaptation must be tailored to the most susceptible individuals and therefore consideration of individual animal responses is essential. Although it appears that most cattle can successfully handle a rapid rate of

grain adaptation, if minimization of acidosis for the most susceptible individuals is desired, a reduced rate of grain adaptation for the entire group is necessary.

A second trial was completed simultaneous to the metabolism trial to investigate effects of the number of step-up diets fed during grain adaptation on feeding behaviour and growth performance of cattle. Methods of rapid and gradual grain adaptation were identical to methods in the previously discussed metabolism trial. In addition a moderate rate of grain adaptation (dietary transition from 40 to 90% concentrate in 9 days using 5 levels of concentrate) was added to this trial. Measures of feeding behaviour from this trial appeared to be indicative of increased discomfort with rapid grain adaptation. However, the moderate rate of grain adaptation did not appear to result in greater discomfort than did gradual adaptation.

During the second trial, reduced daily bunk attendance and six hour bunk attendance was observed for rapid adapted heifers compared to moderate or gradual adapted heifers following introduction of 65% concentrate. Unlike the step-up to 65% concentrate, the step to 90% concentrate did not result in a decrease of daily bunk attendance for rapid adapted heifers until day 4 and six hour bunk attendance was only lower for rapid than for moderate or gradual heifers during one of the first six 6 h intervals. The maximum intermeal interval followed a similar pattern. On both day 1 and 2 following the increase to 65% concentrate, maximum intermeal interval for rapid adapted heifers was greater than the maximum intermeal interval of all moderate or gradual heifers. However, maximum intermeal interval did not differ between any treatments on either day 1 or 2 following the increase to 90% concentrate. Although rapid grain step-up to 90% concentrate did result in negative feeding behaviour for some

individuals, measured effects of the number of step-up diets on feeding behaviour appeared to be greater following the step to 65% concentrate than following the step to 90% concentrate. Individual feed intake of cattle was not measured during the trial. However, intake for the group did not appear to be related to bunk attendance and average feed intake appeared to be more severely reduced for rapid adapted compared to moderate or gradual adapted cattle following the step to 90% concentrate.

The initially reduced ADG of rapid adapted cattle clearly indicates a negative impact of rapid adaptation on initial performance of cattle. However, subsequent compensation of rapidly adapted heifers for the initially reduced ADG indicates that any acidosis encountered did not impact long term performance. Owens et al. (1998) indicated that a single bout of non-fatal acidosis can have prolonged negative effects on animal growth performance. Any acidosis encountered as a result of rapid grain adaptation during the current finishing trial was not severe enough to reduce long-term growth performance.

It is difficult to assess an absolute minimum time period or number of rations required for successful grain adaptation because the rate of grain adaptation is one of many management aspects which affect the incidence and severity of acidosis. Other important factors influencing acidosis include the rate of starch digestion, feeding of ionophores, feeding behaviour, and additional aspects of bunk management. All factors influencing the development of acidosis interact and should be considered when developing a step-up program. However, it can be concluded that rapid adaptation to a high concentrate diet is not likely to result in increased acidosis for all cattle. Instead rapid adaptation increases the opportunity for individual cases of acidosis to develop in

susceptible individuals. On the other hand, a reduced rate of grain adaptation will not prevent all acidosis from occurring in the most susceptible individuals but this should help to minimize and reduce the severity of any acidosis encountered. It is clear that management of grain adaptation in commercial feedlots is typically based on minimization of acute acidosis among the more susceptible individuals rather than being based on means of the cattle population. Currently no method exists for pre-identification of those individuals which are more highly susceptible to acidosis. Because management is concerned with minimization of acidosis among the more susceptible individuals, consideration of individual animal response is essential for further development of effective strategies to manage acidosis in feedlot cattle.

6.0. LITERATURE CITED

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